# **Pelvimetry of Males from the Western Cape with Rectal Cancer: Anatomical and Clinical Implication**

By

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# ABSTRACT

Colorectal cancer represents an increasing healthcare burden that affects South African males more commonly than females. Surgical intervention, and specifically total mesorectal excision (TME), remains a key modality in the management of rectal cancer. This procedure occurs in the spatially restricted pelvic canal. Observations of increased difficulty during TME on South African males at the Tygerberg Academic Hospital (TH) led to the impression that they display an especially narrow pelvis. Multiple evolutionary factors, such as childbirth, thermoregulation, and bipedal locomotion, have moulded the size of the modern human pelvis, with males naturally displaying a narrower pelvis than female. Climate is geographically structured and is believed to play a pivotal role in pelvic dimensions. Population groups from lower latitudes tend to exhibit a narrower and deeper pelves compared to those from higher latitudes.

The primary aim of the study was to measure the dimensions of the bony pelvis in males from the Western Cape who have undergone potentially curative colorectal cancer surgery at TH, and to compare these results with other ecogeographical regions. Secondarily, it aimed to determine if an association exists between pelvic dimensions and morbidity documented in rectal cancers patients who have undergone a TME at TH.

Pelvic size was investigated by conducting nineteen pelvimetric measurements on 3D bony pelvic reconstructions of male patients (n=158) using computed tomography data. Thereafter measurements were compared with other ecogeographical regions to investigate our relative pelvic size and relationships between latitude and pelvic dimensions using forest plots. Lastly, a one-way ANOVA with a post hoc Bonferroni test was performed to determine if significant differences occur in pelvic measurements among different groups of surgical complications.

This population was found to display a relatively narrow transverse pelvic canal when compared to populations from higher latitudes, which was accompanied by an increase in anteroposterior dimensions of the canal. Some measurements were found to follow expected ecogeographical patterns. Significant differences in the inlet anteroposterior measurement were found among patients in some surgical complication groups. However, no relationship between pelvic dimensions and patient morbidity was found.

The transversely narrow true pelvis of this population compared males in other ecogeographical regions may explain the increase TME difficulty during surgery. However,

significant differences in transverse measurements between patients with and without surgical complications were not found. Significant differences were found in the anteroposterior measurement of the canal; however, this measurement was found to be larger than humans from higher latitude regions. No relationships between pelvic dimensions and surgical complications were identified. These findings hope to assist in identification of patients who present with a narrow pelvis prior to surgery to aid preoperative planning for a potentially more difficult TME. Research could be furthered by comparing patient pelvic measurement with measurements of operative difficulty for this procedure.

# ABSTRAK

Kolorektale kanker verteenwoordig ‘n stygende gesondheidslas wat Suid-Afrikaanse mans meer algemeen affekteer as vroue. Chirurgiese intervensie, en spesifiek totale mesorektale eksisie (TME), bly ‘n sleutelwyse in die hantering van rektale kanker. Die prosedure vind plaas in die ruimtelik beperkte bekkenkanaal. Die waarneming dat daar ‘n meer ingewikkeldheid ervaar word tydens ‘n TME op Suid-Afrikaanse mans by Tygerberg Akademiese Hospitaal (TH), het tot die indruk gelei dat die mans ‘n uitsonderlike vernoude pelvis het. Veelvuldige evolusionêre faktore soos geboorte, termoregulasie en bipedale of tweevoetige voortbeweging, het die grootte van die moderne menslike bekkengordel gevorm, met mans wat ‘n baie nouer bekken toon as vroue. Klimaat is geografies saamgestel en daar word geglo dat dit ‘n belangrike rol speel in pelviese afmetings. Bevolkingsgroepe van ‘n laer breedte graad toon ‘n nouer en dieper bekkengordel in vergelyking met diegene van ‘n hoër breedte graad.

Die primêre doelstelling van die studie was om die afmetings van die bekkengordel in mans van die Wes-Kaap wat potensiële genesende kolorektale chirurgie by TH ondergaan het, te meet. Dit word dan vergelyk met uitslae van ander eko-geografiese areas. Die tweede doelstelling is om ‘n verwantskap te bepaal tussen pelviese afmetings en morbiditeit wat gedokumenteer is in rektale kanker pasiënte wat TME ondergaan het by TH.

Die bekkengordelgrootte was ondersoek deur 19 pelviese afmetings op 3D benige pelviese rekonstruksies van manlike pasiënte (n=158) te meet deur die gebruik van gerekenariseerde tomografiese data. Daarna is die afmetings vergelyk met ander eko-geografiese areas, om sodoende die relatiewe pelviese grootte en verhouding tussen breedte graad en pelviese dimensies te ondersoek. Hierdie data is met forest stippings aangedui. Laastens is ‘n een rigting ANOVA met ‘n post hoc Bonferroni toets gedoen om te bepaal of betekenisvolle verskille voorkom in pelviese afmetings tussen verskillende groepe met chirurgiese komplikasies.

Hierdie bevolkingsgroep toon ‘n relatiewe nou transversale bekkenkanaal, as dit vergelyk word met hoër breedte grade, tesame met ‘n verhoogde anteroposterior afmetings van die kanaal. Sekere meetings het verwagte eko-geografiese patrone gevolg. Betekenisvolle verskille was opgemerk in die bekkeninlaat se anteroposterior afmetings in pasiënte in sekere chirurgiese komplikasie groepe. Daar is egter geen verhouding tussen pelviese afmetings en pasiënt morbiditeit nie.

Die nou dwarsafmetings van die ware pelvis van hierdie populasie in vergelyking met mans van ander eko-geografiese areas kan die moeilikheidsgraad van die TME vergroot tydens chirurgie. Daar is egter geen betekenisvolle verskille in transversale afmetings tussen pasiënte met of sonder chirurgiese komplikasies gevind nie. Betekenisvolle verskille is gevind in die anteroposterior afmeting van die kanaal, hierdie afmeting was egter groter as in mense van hoër breedte graad areas. Geen verhouding is gevind tussen pelviese dimensies en chirurgiese komplikasies nie. Hierdie bevindinge hoop om van hulp te wees in identifikasie van pasiënte wat voordoen met nou bekkengordels voor chirurgie, om pre-operatiewe beplanning te fasiliteer vir n potensiële moeilike TME. Pasiënt pelviese afmeting kan vergelyk word met meting van die moeilikheidsgraad van 'n prosedure vir toekomstige navorsingprojekte.

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# ABBREVIATIONS

| | |
|---|---|
| Abdominoperineal | AP |
| Anterior resection | AR |
| Body mass index | BMI |
| Chemoradiotherapy | CRT |
| Computed tomography | CT |
| Confidence interval | CI |
| Coronavirus disease 2019COVID-19 | COVID-19 |
| Clavien-Dindo | CD |
| Double stapling technique | DST |
| Greater sciatic notch | GSN |
| Human Research Ethics Committee | HREC |
| Local recurrence | LR |
| Mean difference | MD |
| Multidisciplinary team | MDT |
| Magnetic resonance imaging | MRI |
| North | N |
| Phillips IntelliSpace Portal | PISP |
| Picture archiving and communication system | PACS |
| Radiotherapy | RT |
| Research Electronic Data Capture | REDCap |
| South | S |
| Standard deviation | SD |
| Three-dimensional | 3D |
| Total Mesorectal Excision | TME |
| Transanal endoscopic microsurgery | TEM |
| Tygerberg Academic Hospital | TH |

# CHAPTER 1: INTRODUCTION

## 1.1 BACKGROUND

Colorectal cancer is a major cause of cancer-related deaths world-wide, and in a South African context, it is the fourth most common cancer and sixth most lethal, with a higher incidence in males (Staib, Link, Blatz & Beger, 2002; Mqoqi, Kellett, Freddy & Jula, 2005; National Institute for Communicable Diseases, 2014; Guren, Kørner, Pfeffer, Myklebust, Eriksen, Edna, Larsen, Knudsen, Nesbakken, Wasmuth, Vonen, Hofsli, Færden, Brændengen, Dahl, Steigen, Johansen, Lindsetmo, Drolsum, Tollåli, Dørum, Møller & Wibe, 2015; Zhou, Su, Hu, Su, Ye, Huang, Yu, Li, Zhou, Ni, Jiang & Lou, 2016; Brand, Gaylard & Ramos, 2018). Surgical intervention remains a key modality in the management of this condition (Brown, Kirkham, Williams, Bourne, Radcliffe, Sayman, Newell, Sinnatamby & Heald, 2004; Zhou *et al.*, 2016). At the Tygerberg Academic Hospital (TH), observations made during colorectal procedures led to the impression that males from the Western Cape (WC) seem to have a narrower pelvis compared to males from other ecogeographical regions; ecogeographic variation addresses relationships between geography and physical traits in the context of climate (Mayr, 1956; Roseman & Auerbach, 2015). This is turn led to the impression of greater difficulty in performing colorectal procedures on this population. It is essential to understand how an individual's anatomy may affect surgical outcomes. Literature regarding the size of the male pelvis in South Africa, and specifically the Western Cape, is lacking.

Aims in colorectal cancer management are to provide treatment with the lowest risk of residual disease in the pelvis and to preserve good sphincter function (Glimelius, Tiret, Cervantes & Arnold, 2013). Since its development in the 1970s, the total mesorectal excision (TME) remains the standard surgical approach to rectal tumour excision (Heald, Morna, Ryall, Sexton & Macfarlane, 1998; Baek, Kim, Cho, Bae, Hur, Min, Baik, Lee & Kim, 2015). This is a challenging surgical procedure, involving complex anatomy and multiple sites of surgical dissection within the narrow pelvic cavity (Delibegovic, 2017). An especially narrow pelvis may increase difficulty in maintaining a clear surgical field, recognising precise anatomy, accurately mobilising and excising the rectum, and ultimately affect surgical outcome (Baek *et al.*, 2015; Zhou *et al.*, 2016).

Climate is geographically structured and is believed to influence natural selection on the human body form. The width and depth of the pelvis affect the body's ability to regulate body temperature which plays an important role in determining body proportions (Mayr, 1956; Roseman & Auerbach, 2015). Population groups from lower latitudes tend to exhibit a narrower pelvic breadth, smaller or more elongated bodies, and relatively longer limbs, whilst those from higher latitudes tend to exhibit a wider pelvic breadth and a relatively larger body (Betti, 2017a). This may play a pivotal role in the size of the South African male pelvis.

This research aims to analyse the pelvic girdle of males who have undergone colorectal cancer surgery and to determine if the male pelvis in South Africa is narrow in comparison to other ecogeographic regions, in particular areas experiencing a cooler climate. This was done by measuring the size of male colorectal cancer patients from TH and comparing the results with other regions. Furthermore, it aims to investigate if pelvic confinement is causing surgical difficulties commonly experienced in the South African setting by comparing pelvis dimensions with patient morbidity. It is hoped that the findings will facilitate pre- and intraoperative decision-making for pelvic and perineal procedures, specifically in a Southern African context.

## 1.2 HYPOTHESES, AIMS, AND OBJECTIVES

### 1.2.1 Anatomical investigation: Hypothesis

The focal aim of the study is understanding the bony pelvic anatomy of South African males from the WC. South Africa experiences a hot climate, and climate is thought to have an evolutionary effect on the bony pelvis due to thermoregulatory needs of the body. Thus, it is hypothesised that the bony pelvis of males from the WC is narrower than that of males from ecogeographical regions situated at a higher latitude, experiencing a cooler climate.

### 1.2.2 Anatomical investigation: Aim

The primary aim is to objectively measure the dimensions of the bony pelvis in males from the Western Cape who have undergone potentially curative colorectal cancer surgery at TH, and to compare these results with other ecogeographical regions. This will provide intel into South African male pelvic anatomy and investigate if its dimensions are narrow in comparison to other locations, particularly those experiencing a cooler climate.

### 1.2.3 Anatomical investigation: Objectives

In order to achieve the above aim, the following objectives were carried out:

1. To measure pelvic dimensions from computed tomography (CT) scans of colorectal cancer surgery patients from TH using a three-dimensions (3D) reconstruction of the pelvis on Phillips IntelliSpace Portal (PISP) software.

2. To describe bony pelvic anatomy of this population using descriptive statistics.
3. To obtain pelvimetric data from as many ecogeographical regions as possible using published literature
4. To compare pelvic dimensions of the studied population with other ecogeographical regions by producing forest plots.

### 1.2.4 Clinical investigation: Hypothesis

Colorectal clinicians from TH have expressed difficulty in surgical technique during TME on some of our population, and it is believed that this is due to a narrow pelvic canal. Difficulty in visualising, mobilising, and excising pelvic structures during this procedure may increase surgical complications and patient morbidity. Thus, it is further hypothesised that there is an association between pelvic dimensions and surgical complications documented in male patients who have undergone TME at TH.

### 1.2.5 Clinical investigation: Aim

The secondary aim of the research is to determine if there is an association between pelvic dimensions and morbidity documented in rectal cancers patients who have undergone a TME at TH. This will indicate if decreased pelvic dimensions are increasing operative difficulty.

### 1.2.6 Clinical investigation: Objectives

In order to achieve the above aim, the following objectives were carried out:

1. Obtain surgical complications documented in TME patients from previous research carried out at the hospital
2. To statistically assess the association between pelvic dimensions with surgical complications

# CHAPTER 2: LITERATURE REVIEW

## 2.1 BONY PELVIC ANATOMY

The pelvis is an infero-posterior extension of the abdomen and is a transitional region between the trunk and the lower limbs. This cavity is bounded by the pelvic girdle, a basin-shaped ring of bones forming part of the appendicular skeleton, as well as the ligamentous and muscular pelvic walls and floor. It can be subdivided into the greater, or false, and lesser, or true pelvis, by the pelvic brim (Raizada & Mittal, 2008; Moore, Dalley & Agur, 2014). The greater pelvis is surrounded by the superior pelvic girdle, contains the inferior abdominal organs, and offers protection thereof. The lesser pelvis, surrounded by the inferior pelvic girdle, provides the skeletal framework for the pelvic cavity and the perineum (Moore *et al.*, 2014).

The contents of the pelvic cavity include the pelvic genital organs, rectum, urinary bladder, ureters, blood vessels, nerves, and lymphatics. It may also contain inferior portions of abdominal visceral, such as loops of the small intestine, and more frequently, the large intestine (Moore *et al.*, 2014). The cavity is limited inferiorly by the musculofascial pelvic diaphragm which forms a bowl-like pelvic floor (Hansen, 2010). The perineum and pelvic cavity are both compartments of the trunk separated by this musculofascial pelvic diaphragm. The perineum includes the space between the thighs and the buttocks that extends from the pubis to the coccyx, as well as the shallow compartment deep to this area but inferior to the pelvic diaphragm (Moore *et al.*, 2014).

### 2.1.1 The bony pelvis

The pelvic girdle is composed of two hip bones, the sacrum, and the coccyx. This rigid bony structure connects the vertebral column to the femora, provides sites for muscle attachment, bears the weight of the upper body and transfers this weight to the legs (Ger, 1988; Hansen, 2010; Ansede, Mitchell & Healy, 2012; Moore *et al.*, 2014). Other functions include the containment, support, and protection of inferior abdominal and pelvic viscera, providing attachment for erectile bodies of the external genitalia, and allowing for childbirth in females (Desilva & Rosenberg, 2017).

The hip bones, or os coxae, are large and irregularly shaped bones, consisting of an ilium, ischium, and pubis. In children, the three bones are connected by the triradiate cartilage at the acetabulum and later fuse during puberty (Sanders, 2007; Raizada & Mittal, 2008; Moore *et al.*, 2014). The acetabulum is the socket wherein the femur head articulates and the point where the three bones unite is known as Schultz Point A, characterised by irregular bone and a notch (Raizada & Mittal, 2008; Kurki, 2013a). Each ilium articulates with the sacrum posteriorly and the pubic bones articulate anteriorly in the midline with the fixed pubic symphysis, forming the ring of bones. The medial surface or internal aspect of the hip bones form the boundaries of the pelvic cavity. The lateral surface, or external aspect, is primarily involved in providing attachment sites for the musculature of the lower limbs (Sanders, 2007; Moore *et al.*, 2014).

The ilium is a fan-shaped bone forming the superior portion of the hip bone. The ala, or wing, of the ilium, can be visualised as a spread-out fan, and the body of the bone as the handle. The iliac fossa is formed by the anteromedial concave surface of the ala, and superiorly, the iliac crest follows the curve of the ala between the posterior and anterior superior iliac spines (Sanders, 2007; Moore *et al.*, 2014). Posteriorly, the ilium has a sacropelvic surface which consists of an auricular surface and iliac tuberosity that articulate with the sacrum with a synovial and syndesmotic joint respectively. The lateral iliac surface forms part of the acetabulum (Ansede *et al.*, 2012; Moore *et al.*, 2014).

The ischium forms the infero-posterior portion of the hip bone and consists of a body and ramus. The more superior body forms part of the acetabulum, while the more inferior ramus forms part of the obturator foramen. Infero-posteriorly, the ischium terminates as the large ischial tuberosity (Sanders, 2007; Moore *et al.*, 2014). Near the junction of the body and ramus, a small, posteromedial projection exists, known as the ischial spine. The concavity inferior to this projection is known as the lesser sciatic notch. Superiorly a larger concavity exists, known as the greater sciatic notch (GSN), which is formed in part by the body of the ischium (Moore *et al.*, 2014).

The pubis is an angulated bone forming the infero-anterior hip bone. It consists of a body, and both a superior and inferior ramus, with the superior forming part of the acetabulum, and the inferior forming part of the obturator foramen. The body has an anterior thickening, forming the pubic crest, which extends laterally as the pubic tubercle (Sanders, 2007; Moore *et al.*, 2014).

The sacrum is an inverted triangular-shaped bone, consisting of five fused sacral vertebrae. The superior surface, or the promontory, articulates with the inferior surface of the fifth lumbar vertebra (Ger, 1988; Hansen, 2010; Ansede *et al.*, 2012; Moore *et al.*, 2014). It has a sacral canal which is a downward continuation of the vertebral canal and houses five anterior and posterior sacral nerves, as well as coccygeal nerves. Sacral development is important in the aetiology of rectal prolapse; in children, the sacral curve is poorly developed, causing a straight rectum which is prone to suffer the effects of positive intra-abdominal pressure (Ger, 1988).

The coccyx is also an inverted triangular-shaped bone, consisting of three to five coccygeal vertebrae and is a remnant of the embryonic tail. The fifth sacral segment and first coccygeal segment articulate at the sacrococcygeal joint, which commonly fuses. Two coccygeal cornua project superiorly to meet the two sacral cornua which project inferiorly (Ger, 1988; Hansen, 2010).

### 2.1.2 Pelvimetry

Pelvimetry is the measurement of bony pelvic dimensions and is most commonly applied in the evaluation of cephalopelvic disproportion when assessing the need for performing a Caesarean section during pregnancy (Boyle, Petty, Chalmers, Quirke, Cairns, Finan, Sagar & Burke, 2005; Sanders, 2007; Lenhard, Johnson, Weckbach, Nikolaou, Friese & Hasbargen, 2009). However, such measures can be applied in various disciplines when assessing pelvic confinement by measuring pelvic planes (Boyle *et al.*, 2005; Neill, Lockwood, McCluskey & Fleshner, 2006). In colorectal surgery, pelvimetry has recently been employed in research addressing technical difficulties of the TME and trying to predict surgical outcomes (Boyle *et al.*, 2005; Salerno, Daniels, Brown, Heald & Moran, 2006; Salerno, Daniels, Brown, Norman, Moran & Heald, 2007; Targarona, Balague & Pernas, 2008; Wang, Xiao, Qiu, Yao & Pan, 2014; Zhou *et al.*, 2016; zur Hausen, Gröne, Kaufmann, Niehues, Aschenbrenner, Stroux, Hamm, Kreis & Lauscher, 2017).

There are four planes of the pelvic canal that are commonly analysed using pelvimetry: the inlet to the true pelvis; two midplanes; and the outlet. The inlet is formed by the linea terminalis. The first midplane is formed anteriorly by the midpoint of the pubic symphysis, laterally by the acetabulum centres, and posteriorly by the transverse ridge between the second and third sacral segments; it is the widest plane of the pelvic cavity (Tague, 1995; Kolesova & Vetra, 2011; Kurki, 2013a). The second midplane is formed anteriorly by the lower border of the pubic symphysis, laterally by the ischial spines, and posteriorly by the transverse ridge between the fourth and fifth sacral segments. The outlet is formed anteriorly by the lower border of the pubic symphysis, laterally by the pubic rami and ischial tuberosities, and posteriorly by the tip of the coccyx (Figure 3.1) (Tague, 1995; Kolesova & Vetra, 2011; Kurki, 2013).

A variety of imaging modalities can be used to assess bone structure, such as plain X-rays, CT, and magnetic resonance imaging (MRI) (Genant, Engelke & Prevrhal, 2008). Although radiation exposure to radiosensitive tissue, such as the testes, should be avoided, CT remains the favourable modality for assessing anatomy and pathology of the pelvis in trauma settings

(Patel & Verma, 2012). Computed tomography is an accurate and reliable method of obtaining pelvic measurements (Lenhard *et al.*, 2009). It is more widely available, easier to operate, and faster to use compared to MRI (Genant *et al.*, 2008). Research by Lenhard *et al*. (2009) tested various methods of using CT imaging to measure the pelvis and showed that 3D volume-rendered images reconstructed from CT slices are the most precise approach, with reconstructions produced from 1mm scan increments being more accurate than those produced from 5mm increments (Lenhard *et al.*, 2009)**.**

### 2.1.3 Variation of the pelvis

Humans, like other species, display much variation in body form. Four major factors cause skeletal variation; ontogeny, sex, geographical position, and normal variation (White, Black & Folkens, 2012). Ontogeny, or growth, is a source of variation as changes in shape and size of skeletal elements occur along the continuum of growth between foetus and adult. Sexual dimorphism in body size and shape occurs between humans, with females generally exhibiting smaller bones and teeth than males (White *et al.*, 2012). However, the pelvis is an exception to this generalisation; the female body was required to adapt due to encephalisation of neonates thus, the female pelvis is wider than males due to childbirth (Gruss & Schmitt, 2015; Wells, DeSilva & Stock, 2012). Geographic, or population-based variation, causes differences in skeletal and dental characteristics in human groups from differing geographic regions. Geographic variation is often applied in forensic anthropology to estimate the geographic, sometimes referred to as a population group, affinity of unknown skeletal remains (White *et al.*, 2012). Normal variation occurs between different individuals of the same sex, age, and population, and this is sometimes referred to as an individual or idiosyncratic variation (White *et al.*, 2012). Appendix A shows variation in pelvimetric measurements on a global scale.

#### 2.1.3.1 Evolutionary factors that have moulded the pelvis

The pelvis plays a pivotal role in several biological processes, including bipedal locomotion, thermoregulation, and parturition in females. These processes are under strong pressure from natural selection as they are essential for survival and successful reproduction (Gruss & Schmitt, 2015). Modern humans show a relative decrease in pelvic width in relation to total body size compared to early small hominids. Fossilised remains of early hominids from East and South Africa displayed a very broad, and short pelvis (Tague & Lovejoy, 1986; Ruff, 1991;). The pelvic girdle has evolutionarily been moulded by multiple influencing factors, such as demands of locomotion, support of viscera, climatic adaptation, genetic constraints, and childbirth in females (Grabowski, 2013; Warrener, Lewton, Pontzer & Lieberman, 2015).

The level of phenotypic variability displayed by a species depends on the relationship between plasticity and constraints; with plasticity referring to the ability of an organism to adapt to a stimulus, and constraints referring to developmental, selective, and genetic limitations on morphology (Grabowski, 2013; Kurki, 2013a). More plasticity within a species results in more intraspecific variability which can be classified as sexual dimorphism, as well as intra- and interpopulation variation. Evolutionary constraints of the pelvis result from the interaction between selective pressure and genetic constraints (Kurki, 2013a).

Erect, bipedal locomotion warranted the evolution of the pelvis to allow for the ability to balance the upper body on long extended limbs (Gruss & Schmitt, 2015). A narrow pelvis is thought to increase locomotor efficiency (Kurki, 2013b). Experimental research using a dynamic model of hip abductor mechanics, however, showed that locomotor mechanics are unaffected by pelvic width and that the locomotion of male and females are equally efficient (Warrener *et al.*, 2015). Demands of locomotor efficiency experienced by a population are not thought to cause any evolutionary pressure on the width of the pelvis as the efficiency is unaffected by pelvic width. Thus, locomotor efficiency is not viewed as a factor involved in the development of pelvic variation between population groups.

A prominent topic in the literature regarding body shape and size is the study of ecogeographic variation which addresses associations between phenotypes and geographical regions in the context of climate (Schreider, 1950, 1964, 1975; Hanna & Brown, 1983; Ruff, 1991, 1994, 2010; Roseman & Auerbach, 2015; Betti, 2017a, 2017b; Betti & Manica, 2018). Climate, which is geographically structured, is believed to influence natural selection on human body form (Roseman & Auerbach, 2015). Thermoregulatory constraints refer to selective constraints that are caused by the ecological relationship between the environment and a population (Grabowski, 2013). Ecogeographic patterns in body size and shape have been detailed in various endothermic organisms such as humans, hares, passerine birds, and macaques (Roseman & Auerbach, 2015). The width and depth of the pelvis affect the body's ability to regulate body temperature which plays an important role in determining body proportions and surface area-to-mass-ratio, thus influencing heat lost through the body surface (Gruss & Schmitt, 2015; Ruff, 1994). Ruff (1991) argues that the decrease in pelvic breadth displayed by modern humans may be due to climate, along with the allometric consequences of increased body size. According to the basic principles of thermoregulation, to maintain a constant surface area/body mass ratio, absolute body breadth should remain constant, despite changes in body height. Patterns of variation of the pelvis of modern humans support this prediction (Ruff, 1991; Ruff, 1994). Research has shown that populations from different climates often exhibit different body proportions. Population groups from lower latitudes tend to exhibit a narrower pelvic breadth, smaller or more elongated bodies, and relatively longer limbs, whilst those from higher latitudes tend to exhibit a wider pelvic breadth and a relatively larger body (Betti, 2017a, 2017b). Thus, as South Africa is situated at a low latitude and displays a hot climate, its residing population groups are expected to exhibit relatively narrow pelves.

## 2.2 RECTAL CANCER MANAGEMENT

### 2.2.1 Background

In South Africa in 1999, colorectal cancer was found to be the fourth leading cancer in males, and it was found that males had a 60% greater risk of developing colorectal cancer than females (Mqoqi *et al.*, 2005). Data from the 2014 National Cancer Registry showed that it was still the fourth most common cancer in South African males, accounting for 5,3% of all histologically diagnosed cancers while being the sixth most common cancer in South African females, accounting for 4,3% (National Institute for Communicable Diseases, 2014). Risk factors for colorectal cancer include age, lifestyle, and predisposing conditions. Increased age, smoking, at least moderate alcohol consumption, and excessive processed or red meat consumption may increase risks, while dietary and the regular use of non-steroidal anti-inflammatory drugs are believed to reduce them (Kirkegaard, Johnsen, Christensen, Overvad & Tjønneland, 2010; Glimelius *et al.*, 2013). Conditions such as type II Diabetes mellitus, Crohn's disease, and Ulcerative colitis also increase the risk of colorectal cancer development. A hereditary component is present in up to roughly 15% of cases, with the most common disorders including familial adenomatous polyposis and Lynch syndrome (Glimelius *et al.*, 2013).

Adenocarcinomas, usually arising from an adenoma, account for 95-98% of rectal carcinomas. During a diagnostic work-up in primary rectal cancer, the location or distance of the tumour from anal verge is measured, morphological verification is conducted, the tumour is staged (according to the TNM staging system), and evaluation of the findings is conducted with a multidisciplinary team (MDT) conference (Glimelius *et al.*, 2013).

### 2.2.2 Management of disease

The aims in the management of the disease are to provide treatment with the lowest risk of residual disease in the pelvis, as this frequently leads to local recurrence (LR), as well as preserving good sphincter function (Glimelius *et al.*, 2013). There is concern regarding the rate of LR of 20-45%, as this cancer is one of the leading cause of cancer-related deaths worldwide (MacFarlane, Ryall & Heald, 1993; Staib, Link, Blatz & Beger, 2002; Zhou *et al.*, 2016). The local recurrence rate is an important measure of the success of operation for rectal cancer (Heald, Husband & Ryall, 1982), furthermore, local and pelvic recurrence may cause major morbidities and lead to mortality (Ooi, Tjandra & Green, 1999).

Rectal cancers can be divided into four groups which allow for risk-adapted treatment, namely: very early; early; intermediate, and locally advanced. These groups are based on clinical T stage of the tumour, as well as tumour height, clinical N stage, anterior location, size of mesorectum, the distance of tumour or lymph node growths from the mesorectal fascia, and vascular or nerve invasion (Glimelius *et al.*, 2013). Earliest cases may be approached surgically with a local excision such as transanal endoscopic microsurgery (TEM), early cases usually require radical dissection employing a total mesorectal excision (TME), intermediate cases warrant the recommendation of neoadjuvant radiotherapy (RT) or chemoradiotherapy (CRT) followed by TME, while locally advanced cases require neoadjuvant CRT and radical surgery (all mentioned treatments are for primary rectal cancer without distant metastasis) (Glimelius *et al.*, 2013).

#### 2.2.2.1 Total mesorectal excision

Surgery remains the cornerstone of treatment for rectal cancer, and the aims are to achieve cure while avoiding LR (Baek *et al.*, 2015; Emile, Lacy, Keller, Martin-perez, Alrawi, Antonio, Chand, Lacy, Martin-perez, Lacy, Lacy & Keller, 2018; Zhou *et al.*, 2016). Surgical intervention in the management of rectal cancer has evolved since the description of abdominoperineal resection by Dr Ernest Miles in 1908 (Emile *et al.*, 2018).

In the past, standard surgical approaches to rectal cancer, including abdominoperineal (AP) and anterior resection (AR), in isolation, produced unsatisfactory resulst in LR and mortality. This prompted the development of neoadjuvant and adjuvant treatment strategies using RT, chemotherapy, or CRT to improve outcomes. In the 1970s the TME was developed to improve surgical outcome and reduce LR, and remains the standard surgical approach to rectal cancer today (Heald *et al.*, 1998; Bennis, Parc, Lefevre, Chafai, Attal & Tiret, 2012; Glimelius *et al.*, 2013; Baek *et al.*, 2015). It was postulated that LR was likely a result of leaving residual mesorectum, rather than of the inherent nature of rectal cancer to spread beyond the confines of perimesorectal dissection (Heald *et al.*, 1998). Foci of adenocarcinoma in the rectum have been demonstrated several centimetres distal from the apparent lower edge of a rectal carcinoma (Heald *et al.*, 1982; MacFarlane *et al.*, 1993). These foci may cause pelvic or suture-line recurrence (Heald *et al.*, 1982).

There are various approaches to a TME, including open, laparoscopic, and transanal. This technique is based on the excision of the rectum and mesorectum within its enveloping fascia as an intact "monobloc," resulting in complete removal of the tumour-containing rectum and its draining lymph nodes (Brown *et al.*, 2004; Heald *et al.*, 1998). In rare situations, such as fragile patients or very early cases, local excision in the form of TEM is preferred over TME (Glimelius *et al.*, 2013).

2.2.2.2 Surgical complications and morbidity associated with total mesorectal excision

Treatment of rectal cancer is challenging and requires skilled practice by the whole MDT, including surgery, pathology, radiation, and chemotherapy (Glimelius *et al.*, 2013). The success of a TME depends on the strength in the skillset of this MDT, patient anatomical factors, and clinical factors. A patient's pelvic anatomy is a crucial factor as the procedure occurs in the confined pelvic cavity. A narrow pelvis may cause difficulty in maintaining a clear surgical field, recognising precise anatomy, and accurately mobilising and excising the rectum (Boyle *et al.*, 2005; Bennis *et al.*, 2012; Baek *et al.*, 2015; Zhou *et al.*, 2016).

Due to the demanding nature of rectal cancer treatment, TME outcome, patient morbidity and mortality rates have been prominent topics in recent literature (Targarona *et al.*, 2008; Akiyoshi *et al.*, 2009; Ogiso & Yamaguchi, 2011; Bennis *et al.*, 2012; Wang *et al.*, 2014; zur Hausen *et al.*, 2017). Operative time and blood loss during surgery have previously been employed as indicators of operative difficulty in research. These may be compared with pelvic measurements to estimate predictive pelvimetry values for potential blood loss and operative time (Zhou *et al.*, 2016). Anteroposterior diameter of the pelvic inlet and outlet, sacrococcygeal distance, sacrococcygeal-pubic angle, pubic symphysis height, and the diameter of the upper pubis to the coccyx have been found to be predictive values for the operative time of TME. Predictive values for blood loss were determined as the anteroposterior diameter of the mid-pelvis, anteroposterior diameter of the pelvic outlet, interspinous diameter, sacropubic distance, and sacral curvature (Zhou *et al.*, 2016).

Dindo *et al.*, (2004) developed a classification of surgical complications. The authors proposed general principles for this classification in 1992, which was later refined in 2004, allowing for the identification of most complications while preventing down-rating of major negative outcomes (Dindo, Demartines & Clavien, 2004). Consensus on methods of reporting surgical complications allows evaluation of a surgeon's work, as well as progress in the surgical speciality fields. Within this classification system, adverse outcomes are differentiated into three categories: complications; failure to cure; and sequelae (Dindo *et al.*, 2004). A complication is any deviation from the normal postoperative course, a sequela is an "after-effect" of a procedure that is inherent to the procedure, and failure to cure is defined as not achieving the original purpose of the procedure, such as incomplete resection of the tumour. The severity grades of the classification system consist of seven categories (Table 3.2). This morbidity scale is a simple, objective, and reproducible approach for assessment of surgical outcomes (Dindo *et al.*, 2004). Some morbidities associated with TME include coloanal anastomotic leak, pelvic abscess, LR, stoma closure, risk of a permanent stoma, perineal bleeding (warranting blood transfusion), infection of the perineal wound, intestinal obstruction, and anorectal dysfunction (Bennis *et al.*, 2012).

## 2.3 SURGICAL ANATOMY OF THE MALE PELVIS WITH RELEVANCE TO TOTAL MESORECTAL EXCISION

### 2.3.1 Surgical anatomy of male pelvic cavity

The rectum is a hollow muscular tube forming the terminal 12-15cm of the digestive tract. It extends from the rectosigmoid junction superiorly at the level of the S3 vertebra, to the anorectal flexure inferiorly, occupying the hollow of the sacrum (Church, Raudkivi & Hill, 1987; Ger, 1988; Hansen, 2010). The rectum passes through the pelvic diaphragm and bends posteriorly at the anorectal flexure to become the anal canal (Hansen, 2010). Posteriorly, the rectum is extraperitoneal, while its anterior surface is intraperitoneal, except for the inferior third which is posteriorly related to the bladder, prostate, and seminal vesicles. The extraperitoneal rectum and perirectal structures are supported and defined by layers of endopelvic fascia. This fascia has a parietal and visceral component (Church *et al.*, 1987).

To better understand the fasciae, one can visualise the pelvis as a two-compartment structure, with a parietal and visceral component. The outer, parietal component includes the bony pelvis and pelvic muscles forming the walls (obturator, piriformis, and coccygeus muscles) and floor (levator ani muscle). The inner, visceral component includes the rectum, bladder, seminal vesicles, and prostate (Havenga, Grossmann, DeRuiter & Wiggers, 2007).

Parietal endopelvic fascia covers the walls and floors of the pelvis, including the obturator, piriformis, coccygeus, and levator ani muscles. This fascia fuses with the sacral periosteum posteriorly towards the midline, with the linea terminalis laterally, and with the posterior body of the pubis anteriorly (Brown *et al.*, 2004; Havenga *et al.*, 2007). The posterior parietal fascia adherent to the sacrum is a tough membrane known as the presacral fascia, which covers various nerves and vessels. Laterally, the fascia is continuous over the piriformis and coccygeus muscles, before traversing to and becoming continuous with the posterolateral aspect of the rectum. This contributes to the lateral ligaments of the rectum (Church *et al.*, 1987; Havenga *et al.*, 2007). Furthermore, a fascial band known as rectosacral fascia passes anteriorly from the fourth sacral segment to the fascia covering the posterior rectum (mesorectal fascia) (Church *et al.*, 1987; Havenga *et al.*, 2007).

Visceral endopelvic fascia envelopes the aforementioned visceral component of the pelvis. Important regions of visceral fascia during rectal dissection include the mesorectal fascia, or fascia propria of the rectum, as well as Devonvilliers' fascia. The mesorectal fascia surrounds the mesorectum, forming a shiny outer surface, and encloses fat, nerves, vessels, and lymphatics (Church *et al.*, 1987; Havenga *et al.*, 2007). An important potential space, known as the retrorectal space lies between the presacral fascia and mesorectal fascia posteriorly. This space contains loose areolar tissue with fat and very little innervation and vasculature, making it an excellent dissection plane to utilise during rectal mobilisation (Church *et al.*, 1987; Brown *et al.*, 2004; Havenga *et al.*, 2007). Anteriorly, Devonvilliers' fascia separates the anterior rectum from the seminal vesicles (Church *et al.*, 1987; Hansen, 2010). The lateral ligaments of the rectum are formed by distal condensation of fasciae, attach the rectum to the lateral pelvic walls, and contain some nerves and vessels ( Church *et al.*, 1987; Brown *et al.*, 2004; Delibegovic, 2017).

### 2.3.2 Surgical technique for total mesorectal excision

Total mesorectal excision begins with proximal dissection, involving the division of the inferior mesenteric artery close to the aorta and mobilisation of the vascular pedicle of the sigmoid mesocolon. Care is taken to preserve the superior hypogastric plexus (Brown *et al.*, 2004; Delibegovic, 2017). Dissection continues inferiorly in the relatively avascular areolar tissue plane (retrorectal space) posterior to the mesorectum at the level of the fourth sacral segment, thus separating the visceral fascia on the mesorectal surface from the presacral parietal fascia. The lateral mesorectal surfaces are then dissected by separating the visceral mesorectal fascia from the parietal fascia of the pelvic lateral walls, during which the hypogastric nerves and inferior hypogastric plexus are carefully preserved (Brown *et al.*, 2004). Further lateral dissection separates the mesorectum from the neurovascular structures running antero-medially towards urogenital structures. Anterior dissection divides the peritoneum anteriorly relative to the rectovesical pouch and dissection continues anteriorly to Devonvillier's fascia, posteriorly related to the seminal vesicles in males. Preservation of the intact superior and inferior hypogastric plexus and hypogastric nerves is crucial to maintain normal bladder and sexual function (Brown *et al.*, 2004; Delibegovic, 2017). The proximal resection line has a relatively wide boundary and is determined through consideration of the rectal blood supply, while the distal resection line is more critical and depends on tumour localisation (Delibegovic, 2017)

# CHAPTER 3: MATERIALS AND METHODS

## 3.1 MATERIALS

This study was designed around observations made during colorectal cancer surgery at TH which led to the impression that males from the WC have especially narrow pelves. This may cause increased difficulty during colorectal procedures, particularly, TME which occurs in the confined pelvic cavity. Thus, it was important that the sample was representative of the male patient population.

Research Electronic Data Capture (REDCap), a secure web application for managing databases, was used to capture all data securely. No identifiable patient data was collected. All patient-data was anonymised. An ethics application was submitted to the Human Research Ethics Committee (HREC) of Stellenbosch University, including requesting a waiver of consent for access to patient scans. The project was accepted with HREC reference number S19/03/058.

### 3.1.1 Anatomical investigation

To investigate bony pelvic size, a sample of male patients (n=158) who have undergone colorectal cancer surgery at TH was used. Computed tomography scans of each patient (n=158) were collected from the hospital's picture archiving and communication system (PACS) and a three-dimensional (3D) reconstruction of each pelvis was produced using Phillips IntelliSpace Portal (PISP) software available at the Radiology Department, Tygerberg Hospital. Pelvimetry was performed on these 3D reconstructions.

### 3.1.2 Clinical investigation

To investigate relationships between pelvic dimensions and morbidity documented in rectal cancers patients, a subgroup of male patients (n=34) was specifically included in the above sample and anatomical investigation. The surgical complications associated with TME had previously been research in this group at TH in a study titled "Enhanced Recovery After Surgery versus Conventional Care for Elective Colorectal Surgery at Tygerberg Hospital" (HREC reference number: S18/09/192). This subgroup was included as the previous research provides clinical data which can be compared with our anatomical data.

### 3.1.3 Patient inclusion and exclusion criteria

Patients meeting the inclusion criteria and exclusion were selected (n=158), which included the 34 patients whose morbidity have previously been described.

Inclusion criteria for patients were as follows:

- Male over the age of 21
- Undergone potentially curative colorectal cancer surgery at TH between 2015-2019

Patient exclusion criteria include:

- Those whose scans did not include the entire pelvis, for example, ischial tuberosities are cut off
- Computed tomography scans missing from the PACS
- Previous pelvic fracture
- Bone metastases or any previous orthopaedic intervention

The latter two points are important exclusion criteria as such phenomena may cause bone growth, remodelling, and affect pelvic morphology.

## 3.2 METHODS

### 3.2.1 Anatomical investigation

To investigate the size of the male pelvis, pelvimetry was performed on 3D pelvic reconstructions (n=158). These were viewed and manipulated using PISP and measurements were taken using a calibrated curser in the measurement toolbox. Measurements taken are summarised in Table 3.1, can be seen in Figure 3.1, and were taken in millimetres to two decimal places (Iscan, 1983; Tague & Lovejoy, 1986; Patriquin, Steyn & Loth, 2002; Kolesova & Vetra, 2011; Kurki, 2013a, 2013b). Descriptive statistics were performed on the age and pelvimetric data captured for each patient, including mean, median, minimum value, maximum value, and standard deviation (SD).

In order to compare the size of the South African male pelvis with that of males from other ecogeographic regions, and to determine if latitude plays an influential role in global trends of pelvic size, forest plots were constructed. This was done by systematically searching the available online literature and congregating all found publications with male pelvimetry that matched measurements taken in the current study. Pelvimetry data, as well as the latitude of each studied population, were captured from the found literature (captured data can be seen in Appendix A). Thereafter, excel was used to tabulate the found data for each measurement separately and produce scatterplots which display the size of the measurement in each population and stratify these measurements by the latitude of the studied population (Figures 4.1-4.10).

***Table 3.1*** *Pelvimetric measurements with definitions.*

| *Measurement* | *Definition* |
|---|---|
| **Os coxa** | |
| 1. Pubic length | From the superior border of the acetabulum at the centre of origin of the iliac blade to the most superior and medial point on pubic crest |
| 2. Pubic width | Dorsal aspect of the bone from the most inferior point on the face of the pubic symphysis, horizontally to the medial aspect of obturator foramen |
| 3. Pubic height | Most superior to most inferior point on pubic symphysis |
| 4. Ischial length | From the superior border of the acetabulum at the centre of origin of the iliac blade, to the base of the ischial tuberosity |
| 5. Acetabulum diameter | From the middle of the ridge on the superior border to the inferior border |
| 6. Obturator foramen height | Inferior most point within foramen to the most superior point at the superior pubic ramus |
| 7. Obturator foramen width | Perpendicular to the height, from the posterior to anterior borders of the foramen |
| 8. Greater sciatic notch width | From the base of ischial spine to the posterior inferior iliac spine stopping at the point before curvature of the spine angles towards the posterior |
| 9. Iliac breadth | Greatest distance from the anterior superior iliac spine to the posterior superior iliac spine |
| 10. Total height of os coxa | The most superior point of the iliac crest to the most inferior point of the ischial tuberosity |
| **Pelvic girdle** | |
| 11. Bi-iliac breadth | Maximum distance between the lateral most projections of the iliac crests |
| 12. Inlet anteroposterior | Between the posterosuperior border of the pubic symphysis and the promontory of the sacrum |
| 13. Inlet transverse | Maximum distance between linea terminalis |
| 14. Midplane anteroposterior I | Between the posterior midpoint of the pubic symphysis and the anterior border of the second and the third sacral vertebrae |
| 15. Midplane transverse I (biacetabular) | Between the middle of acetabula |
| 16. Midplane anteroposterior II | Between the lower border of pubic symphysis and anterior fourth and fifth sacral vertebrae |
| 17. Midplane transverse II (bispinous) | Lowest distance between two ischial spines |
| 18. Outlet anteroposterior | Between the lower border of pubic symphysis and the tip of coccyx |
| 19. Outlet transverse (bituberous) | Maximum distance between the two internal points of ischial tuberosities |

*Measurement definitions from Tague (1986), and Kurki (2007, 2013), Kolesova & Vētra (2011), Patriquin *et al*. (2002), and İşcan (1983).

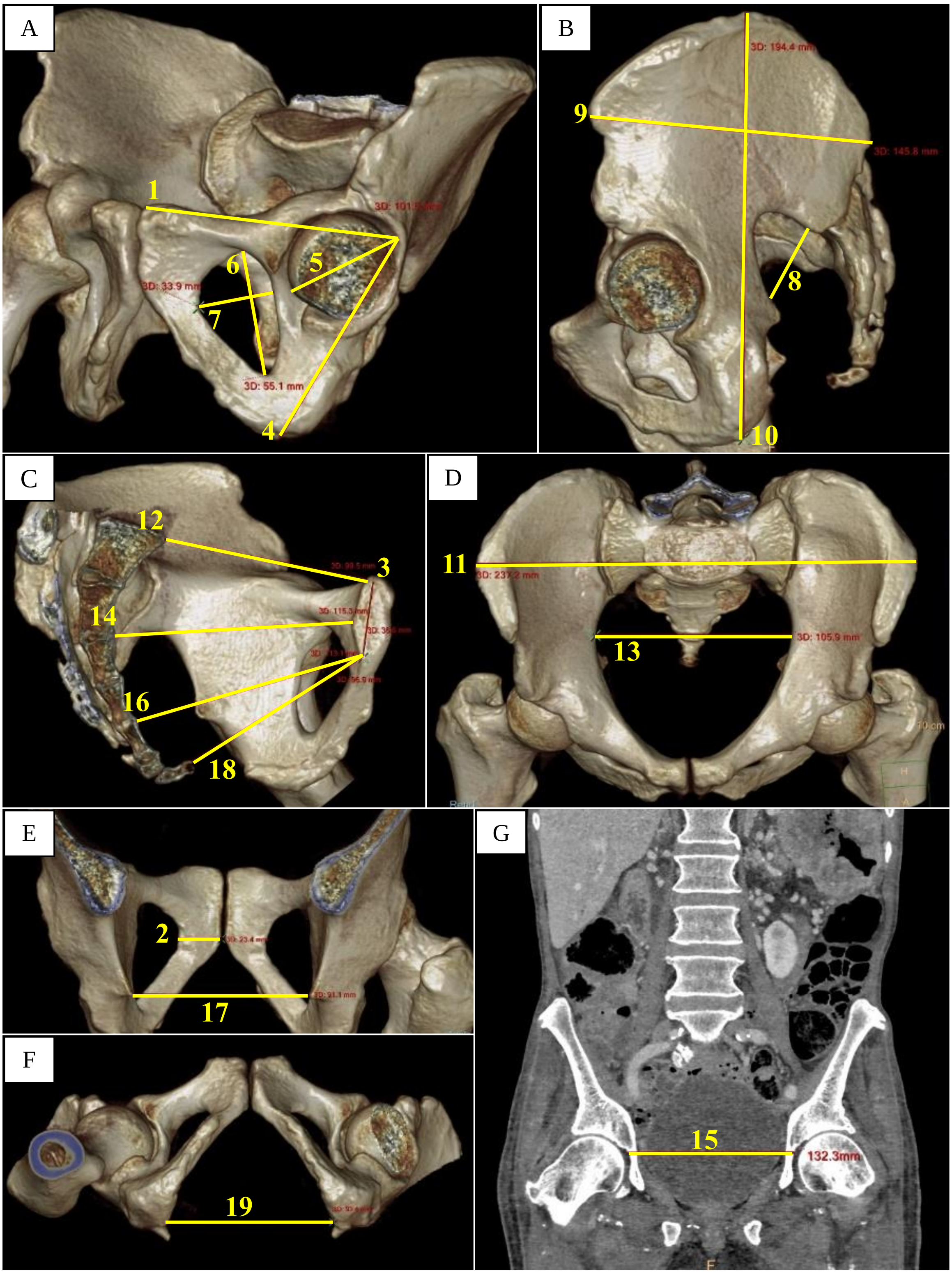


*Figure 3.1 Pelvimetric measurements*

A) Anterolateral view of pelvis (left side); B) Lateral, external view of left hip bone and sacrum; C) Lateral, internal view of left hip bone and sacrum, with right hip bone removed from view; D) Superior view of pelvis; E) Posterior view of pelvis with sacrum cut away, F) Inferior view of pelvis; G) Coronal section through pelvis displaying acetabula.
1) Pubic length; 2) Pubic width; 3) Pubic height; 4) Ischial length; 5) Acetabulum diameter; 6) Obturator foramen height; 7) Obturator foramen width; 8) Greater sciatic notch width; 9) Iliac breadth; 10) Total os coxa height; 11) Bi-iliac breadth; 12) Inlet anteroposterior; 13) Inlet transverse;

14) Midplane anteroposterior I; 15) Biacetabular; 16) Midplane anteroposterior II; 17) Bispinous; 18) Outlet anteroposterior; 19) Bituberous.

#### 3.2.1.1. Intra- and interobserver error

Intra- and interobserver error were calculated following data collection. Pelvimetry was performed a second time on a random 10% of the sample by the primary researcher (intraobserver) as well as an independent researcher (interobserver). A paired samples t-test was performed to investigate the mean differences between the original observations and the second measurements. The null hypothesis tested is that the means differences between the paired observations is zero. Along with the mean differences between measurements, this test yields the 95% confidence interval (CI) and two-tailed p-value, which provide more information regarding the mean differences. No significant results ($p > 0.05$) would indicate acceptable intra- and interobserver agreement and would display that the results are repeatable and reproducible.

### 3.2.2 Clinical investigation

Surgical complications of 34 male patients who have undergone TME at TH have previously been researched and were obtained. Five of these patients met the exclusion criteria and performing pelvimetry was not possible. Pelvimetry was thus performed on 29 of these patients. The complications were classified according to the Clavien-Dindo (CD) system (Table 3.2), which is a grading scale ranging from I-V (Dindo *et al.*, 2004).

***Table 3.2*** *CD classification of surgical complications.*

| *Grade* | *Definition* |
|---|---|
| I | Any deviation from normal postoperative course without need for pharmacological treatment or surgical, endoscopic, and radiological interventions<br>Allowed therapeutic regimens are drugs as antiemetics, antipyretics, analgetics, diuretics, electrolytes, and physiotherapy. This grade also includes wound infections opened at the bedside |
| II | Requiring pharmacological treatment with drugs other than those allowed for grade I<br>Blood transfusions and total parenteral nutrition are also included |
| III | Requiring surgical, endoscopic, or radiological intervention |
| IIIa | Intervention not under general anaesthesia |
| IIIb | Intervention under general anaesthesia |
| IV | Life-threatening complication (Including central nervous system complications) requiring intermediate care/intensive care unit management |
| IVa | Single organ dysfunction |
| IVb | Multiorgan dysfunction |
| V | Death of patient |

| ***Grade*** | ***Definition*** |
| --- | --- |
| Suffix "d" | If the patient suffers from a complication at the time of discharge, the suffix "d" (for "disability") is added to the respective grade of complication, indicating the need for a follow-up to fully evaluate the complication |

In order to investigate the relationship between pelvimetry and morbidity as well as age and morbidity, the mean values for age and each pelvic measurement were calculated for the group of patients without any morbidity, as well as for each CD complication group. The region of the pelvis where confinement would increase difficulty in TME procedure and technique was further investigated. This region being the pelvic canal, which was quantified through transverse and anteroposterior measurements of the canal inlet, two midplanes, and outlet. The relationship between these measurements and patient morbidity was investigated using a one-way ANOVA with a post hoc Bonferroni test. This test was chosen to see if significant differences in canal measurements exist between the observed surgical complications groups and no complications group, as well as between the complication groups. ANOVA is necessary as comparisons of pelvic dimensions need to be made between multiple groups. A post hoc Bonferroni test was required as multiple analyses were made on the same dependent variable (pelvic dimension). Without Bonferroni correction, chances of type I error are increased due to the multiple analyses. The null hypothesis tested is that the differences between pelvic dimension means in surgical complication groups (including none and CD I-V) is zero. This test yields the mean differences between measurements, 95% CI and p-value, which provide more information regarding the mean differences. A p value less than or equal to 0.05 represents significant results and that an association exists between pelvic dimension and a morbidity group.

# CHAPTER 4: RESULTS

## 4.1 ANATOMICAL INVESTIGATION

### 4.1.1 Sample

The sample consisted of 158 male rectal cancer patients who had undergone curative rectal cancer surgery at Tygerberg hospital. The age was normally distributed with a mean of 56.65 years (Table 4.1).

***Table 4.1*** *Age distribution of sample (n=158).*

| | *Age (years)* |
|---|---|
| Mean | 56.65 |
| Median | 58.00 |
| Standard deviation (SD) | 13.63 |
| Minimum | 24.00 |
| Maximum | 83.00 |

### 4.1.2 Pelvimetry

Pelvimetry, consisting of 19 measurements, was performed on the whole sample (Table 4.2). From the unilateral measurements on the left hip bone, the most variable measurement was os coxa height ($\delta$ = 15.59), while the least was pubic width ($\delta$ = 3.20). The most variable measurement on the entire pelvic girdle was the bi-iliac breadth ($\delta$ = 18.25), while midplane transverse II was the least ($\delta$ = 8.38).

***Table 4.2*** *Pelvimetry measurements of study sample (n=158).*

| *Measurement (mm)* | *Mean* | *SD* | *Minimum* | *Maximum* |
|---|---|---|---|---|
| **Left hip bone** | | | | |
| Pubic length | 115.63 | 6.64 | 92.30 | 138.60 |
| Pubic width | 23.77 | 3.20 | 16.70 | 39.90 |
| Pubic height | 35.56 | 4.62 | 24.10 | 48.40 |
| Ischial length | 105.77 | 7.07 | 89.70 | 136.50 |
| Acetabulum diameter | 50.28 | 3.25 | 43.90 | 63.60 |
| Obturator foramen height | 55.17 | 4.35 | 42.70 | 69.20 |
| Obturator foramen width | 33.59 | 3.51 | 23.40 | 45.20 |
| Greater sciatic notch width | 45.08 | 5.63 | 33.50 | 60.10 |
| Os coxa height | 211.69 | 15.59 | 178.20 | 266.10 |
| Iliac breadth | 159.41 | 12.75 | 101.80 | 215.50 |
| **Pelvic girdle** | | | | |
| Bi-iliac breadth | 266.67 | 18.25 | 215.80 | 338.20 |
| Inlet anteroposterior | 107.36 | 12.40 | 39.80 | 142.00 |
| Inlet transverse | 117.93 | 8.63 | 98.90 | 144.80 |
| Midplane anteroposterior I | 117.35 | 11.34 | 86.00 | 158.50 |
| Midplane transverse I | 110.62 | 9.28 | 75.80 | 132.30 |

| *Measurement (mm)* | *Mean* | *SD* | *Minimum* | *Maximum* |
|---|---|---|---|---|
| Midplane anteroposterior II | 119.30 | 9.62 | 82.20 | 146.30 |
| Midplane transverse II | 89.47 | 8.38 | 71.60 | 117.50 |
| Outlet anteroposterior | 93.60 | 10.91 | 66.10 | 127.40 |
| Outlet transverse | 91.39 | 10.11 | 68.50 | 130.30 |

4.1.2.1 Intraobserver error

In order to test intraobserver error, 10% of the sample was chosen at random, and pelvimetry was performed a second time by the primary researcher. Measurements were compared using a paired samples t-test (Table 4.3). No significant differences were found between the measurements ($p > 0.05$), with the exception of outlet transverse diameter ($p = 0.04$)

***Table 4.3*** *Paired t-test results for intraobserver error.*

| | | | | *95% Confidence Interval of the* | | | | |
|---|---|---|---|---|---|---|---|---|
| | *Mean (mm)* | *SD* | *Std. Error Mean* | *Lower* | *Upper* | *t* | *df* | *Sig. (2-tailed)* |
| Pubic length | -0.26 | 2.12 | 0.55 | -1.44 | 0.92 | -0.47 | 14 | 0.64 |
| Pubic width | -0.27 | 1.67 | 0.43 | -0.95 | 0.90 | -0.06 | 14 | 0.95 |
| Pubic height | -0.63 | 2.52 | 0.65 | -2.03 | 0.76 | -0.97 | 14 | 0.34 |
| Ischial length | -0.83 | 2.93 | 0.76 | -2.45 | 0.80 | -1.09 | 14 | 0.29 |
| Acetabulum diameter | 0.05 | 1.66 | 0.43 | -0.87 | 0.96 | 0.11 | 14 | 0.92 |
| Obturator foramen height | 0.26 | 0.74 | 0.19 | -0.15 | 0.67 | 1.36 | 14 | 0.20 |
| Obturator foramen width | -0.56 | 1.31 | 0.34 | -1.29 | 0.16 | -1.66 | 14 | 0.12 |
| Greater sciatic notch width | 0.70 | 2.74 | 0.71 | -0.82 | 2.22 | 0.99 | 14 | 0.34 |
| Iliac breadth | 8.51 | 33.90 | 8.75 | -10.26 | 27.29 | 0.97 | 14 | 0.35 |
| Bi-iliac breadth | -0.56 | 2.03 | 0.52 | -1.69 | 0.57 | -1.07 | 14 | 0.30 |
| Os coxa height | 0.47 | 3.04 | 0.78 | -1.21 | 2.15 | 0.60 | 14 | 0.56 |
| Inlet anteroposterior | -0.14 | 1.01 | 0.26 | -0.70 | 0.42 | -0.54 | 14 | 0.60 |
| Inlet transverse | -0.33 | 1.26 | 0.33 | -1.03 | 0.36 | -1.03 | 14 | 0.32 |
| Midplane anteroposterior I | 0.42 | 2.72 | 0.70 | -1.09 | 1.93 | 0.60 | 14 | 0.56 |
| Midplane transverse I | 0.11 | 1.37 | 0.35 | -0.65 | 0.87 | 0.30 | 14 | 0.77 |
| Midplane anteroposterior II | -1.03 | 2.67 | 0.69 | -2.51 | 0.45 | -1.49 | 14 | 0.16 |
| Midplane transverse II | 0.12 | 1.26 | 0.33 | -0.58 | 0.82 | 0.37 | 14 | 0.72 |
| Outlet anteroposterior | -0.17 | 2.53 | 0.65 | -1.57 | 1.23 | -0.27 | 14 | 0.80 |
| Outlet transverse | 1.36 | 2.33 | 0.60 | 0.07 | 2.65 | 2.26 | 14 | 0.04 |

4.1.2.2. Interobserver error

Similarly, to test interobserver error, 10% of the sample was chosen at random, and pelvimetry was performed a second time by an independent researcher. Measurements were compared using a paired samples t-test to test the mean difference between the two sets of observations (Table 4.4). Significant differences were found between most of the measurements ($p \leq 0.05$), except pubic width ($p = 0.18$), ischial length ($p = 0.71$), iliac breadth ($p = 0.40$), bi-iliac breadth ($p = 0.44$), inlet transverse ($p = 0.08$), and outlet transverse ($p = 0.06$).

***Table 4.4*** *Paired t-test results for interobserver error.*

| | *Mean (mm)* | *SD* | *Std. Error Mean* | *95% Confidence Interval of the Lower* | *Upper* | *t* | *df* | *Sig. (2-tailed)* |
|---|---|---|---|---|---|---|---|---|
| Pubic length | -1.93 | 3.63 | 0.91 | -3.86 | 0.00 | -2.13 | 15 | 0.05 |
| Pubic width | -0.44 | 1.27 | 0.32 | -1.12 | 0.23 | -1.40 | 15 | 0.18 |
| Pubic height | -2.84 | 3.01 | 0.75 | -4.44 | -1.23 | -3.77 | 15 | 0.00 |
| Ischial length | 0.44 | 4.54 | 1.14 | -1.98 | 2.86 | 0.39 | 15 | 0.71 |
| Acetabulum diameter | -9.70 | 10.82 | 2.70 | -15.47 | -3.93 | -3.59 | 15 | 0.00 |
| Obturator foramen height | -1.62 | 1.79 | 0.45 | -2.58 | -0.67 | -3.63 | 15 | 0.00 |
| Obturator foramen width | -2.21 | 1.89 | 0.47 | -3.22 | -1.20 | -4.67 | 15 | 0.00 |
| Greater sciatic notch width | 1.51 | 2.03 | 0.51 | 0.43 | 2.59 | 2.97 | 15 | 0.01 |
| Iliac breadth | -2.68 | 12.37 | 3.09 | -9.27 | 3.91 | -0.87 | 15 | 0.40 |
| Bi-iliac breadth | -0.93 | 4.68 | 1.17 | -3.42 | 1.56 | -0.80 | 15 | 0.44 |
| Os coxa height | -7.48 | 3.84 | 0.96 | -9.53 | -5.44 | -7.80 | 15 | 0.00 |
| Inlet anteroposterior | -3.85 | 2.02 | 0.50 | -4.93 | -2.77 | -7.63 | 15 | 0.00 |
| Inlet transverse | -0.48 | 1.00 | 0.25 | -1.01 | 0.06 | -1.91 | 15 | 0.08 |
| Midplane anteroposterior I | -1.69 | 1.48 | 0.37 | -2.48 | -0.90 | -4.56 | 15 | 0.00 |
| Midplane transverse I | -6.38 | 7.84 | 1.96 | -10.55 | -2.20 | -3.25 | 15 | 0.01 |
| Midplane anteroposterior II | -2.28 | 3.01 | 0.75 | -3.88 | -0.67 | -3.02 | 15 | 0.01 |
| Midplane transverse II | -1.81 | 2.36 | 0.59 | -3.07 | -0.55 | -3.07 | 15 | 0.01 |
| Outlet anteroposterior | -5.39 | 6.7 | 1.59 | -8.78 | -2.00 | -3.39 | 15 | 0.00 |
| Outlet transverse | -8.78 | 16.70 | 4.17 | -17.67 | 0.12 | -2.10 | 15 | 0.06 |

### 4.1.3 Global trends of pelvic dimensions

Of the 19 measurements taken on the studied sample, 10 of these were documented commonly enough in the literature to compare the size of these measurements between different ecogeographical regions. These included inlet anteroposterior (Figure 4.1), inlet transverse (Figure 4.2), midplane anteroposterior II (Figure 4.3), midplane transverse I (Figure 4.4), midplane transverse II (Figure 4.5), outlet anteroposterior (Figure 4.6), outlet transverse (Figure 4.7), os coxa height (Figure 4.8), bi-iliac breadth (Figure 4.9), and pubic height (Figure 4.10). For the figures, each author and latitude coordinate on the left corresponds with a measurement value on the right. A latitude of zero indicates the position of the equator where climate is the hottest, and as the value of this coordinate increases, in the northern or southern direction, distance from the equator increase, and climate get cooler.

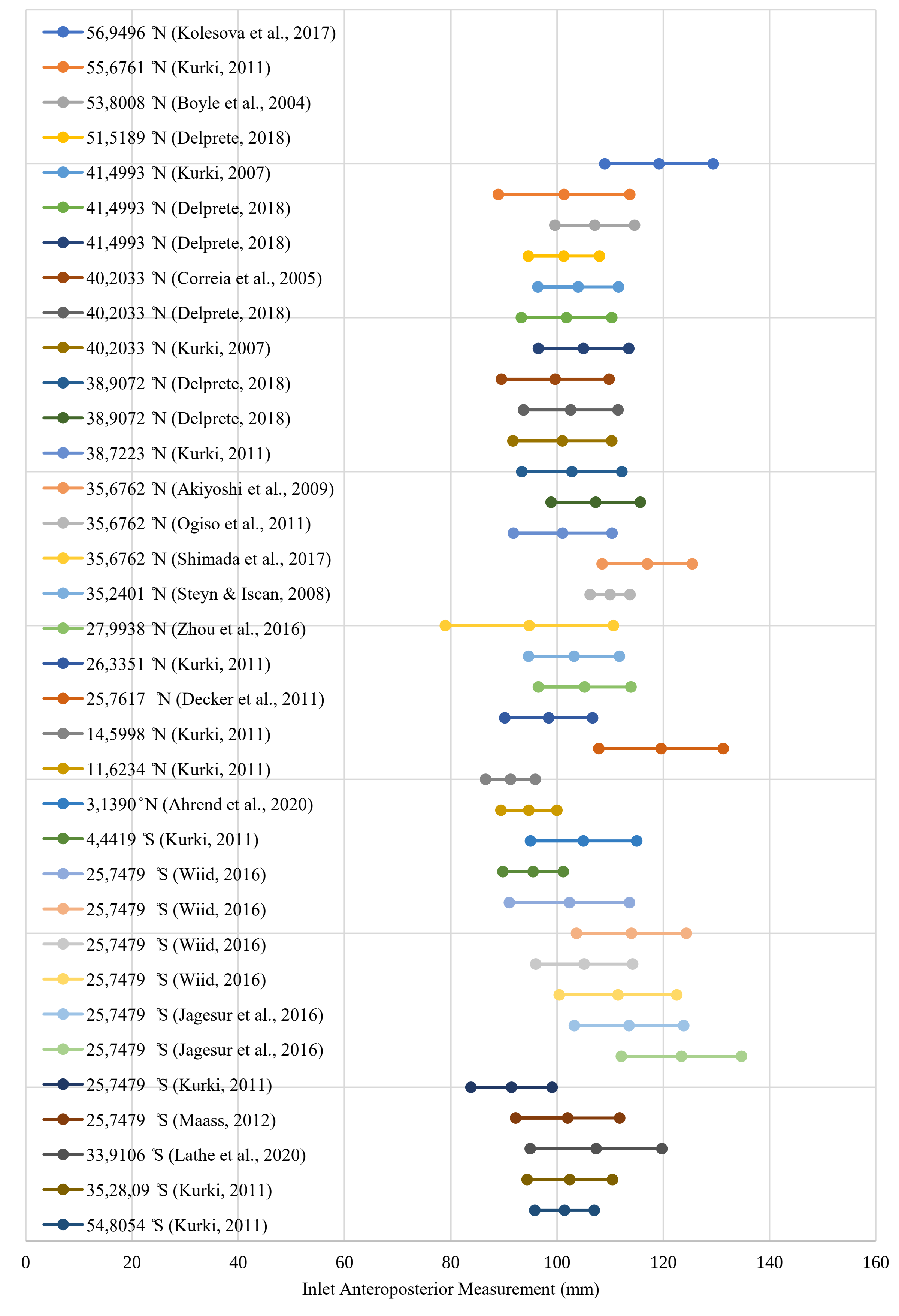


***Figure 4.1*** *Available world-wide data for inlet anterior measurement of pelvis summarised by latitude of studied population (and authors).*

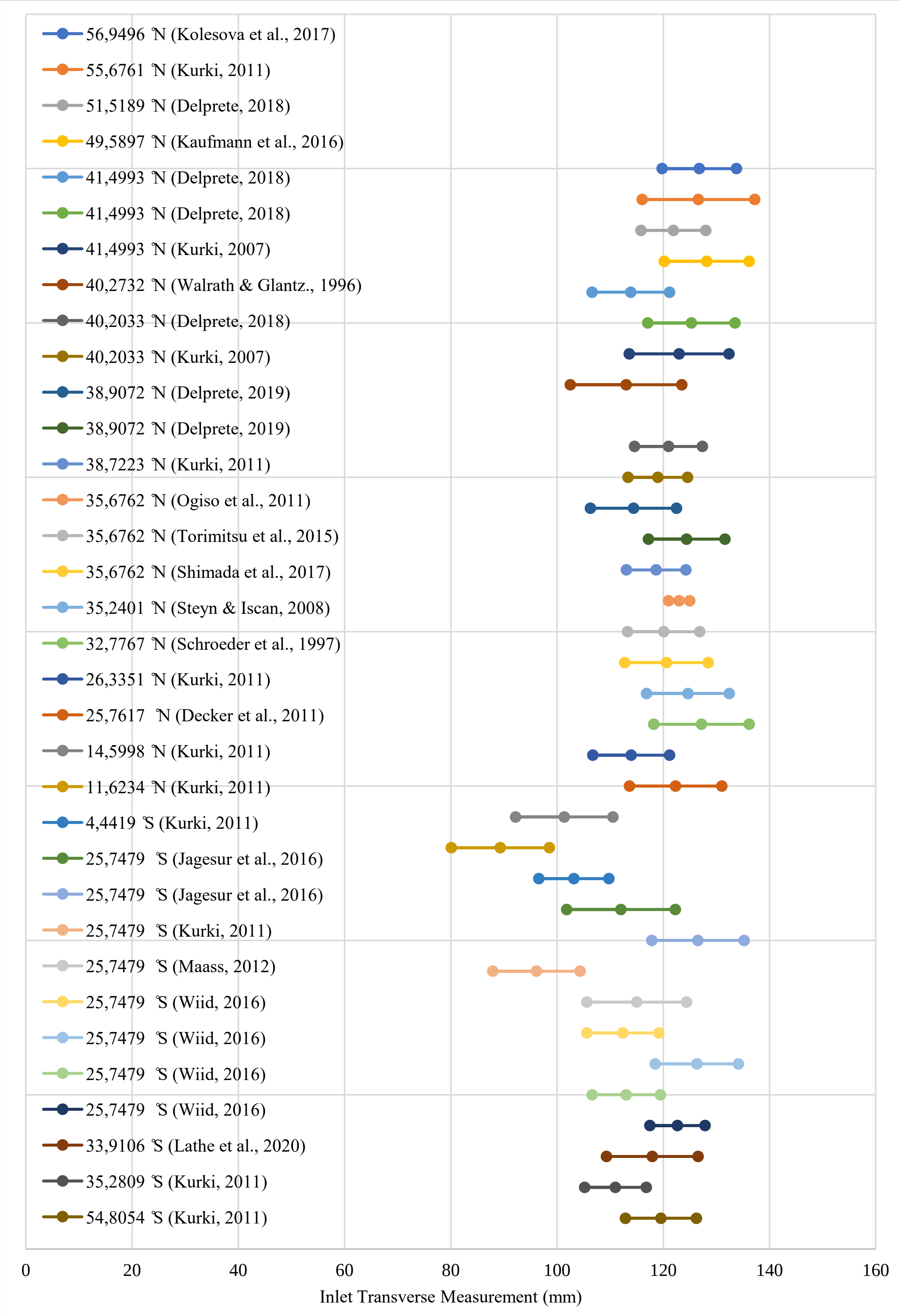


***Figure 4.2*** *Available world-wide data for inlet transverse measurement of pelvis summarised by latitude of studied population (and authors)*

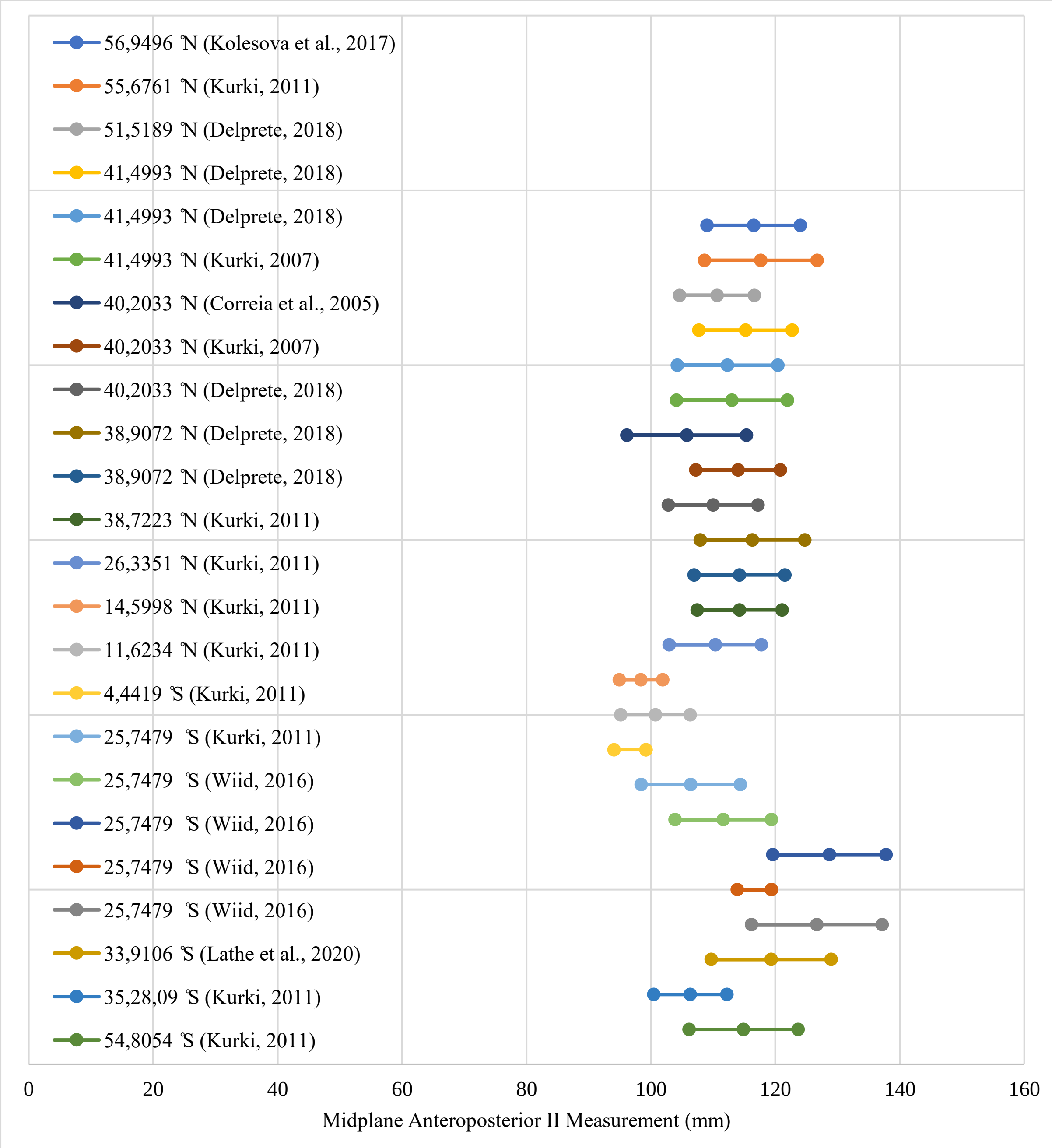


***Figure 4.3*** *Available world-wide data for midplane anteroposterior II measurement of pelvis summarised by latitude of studied population (and authors).*

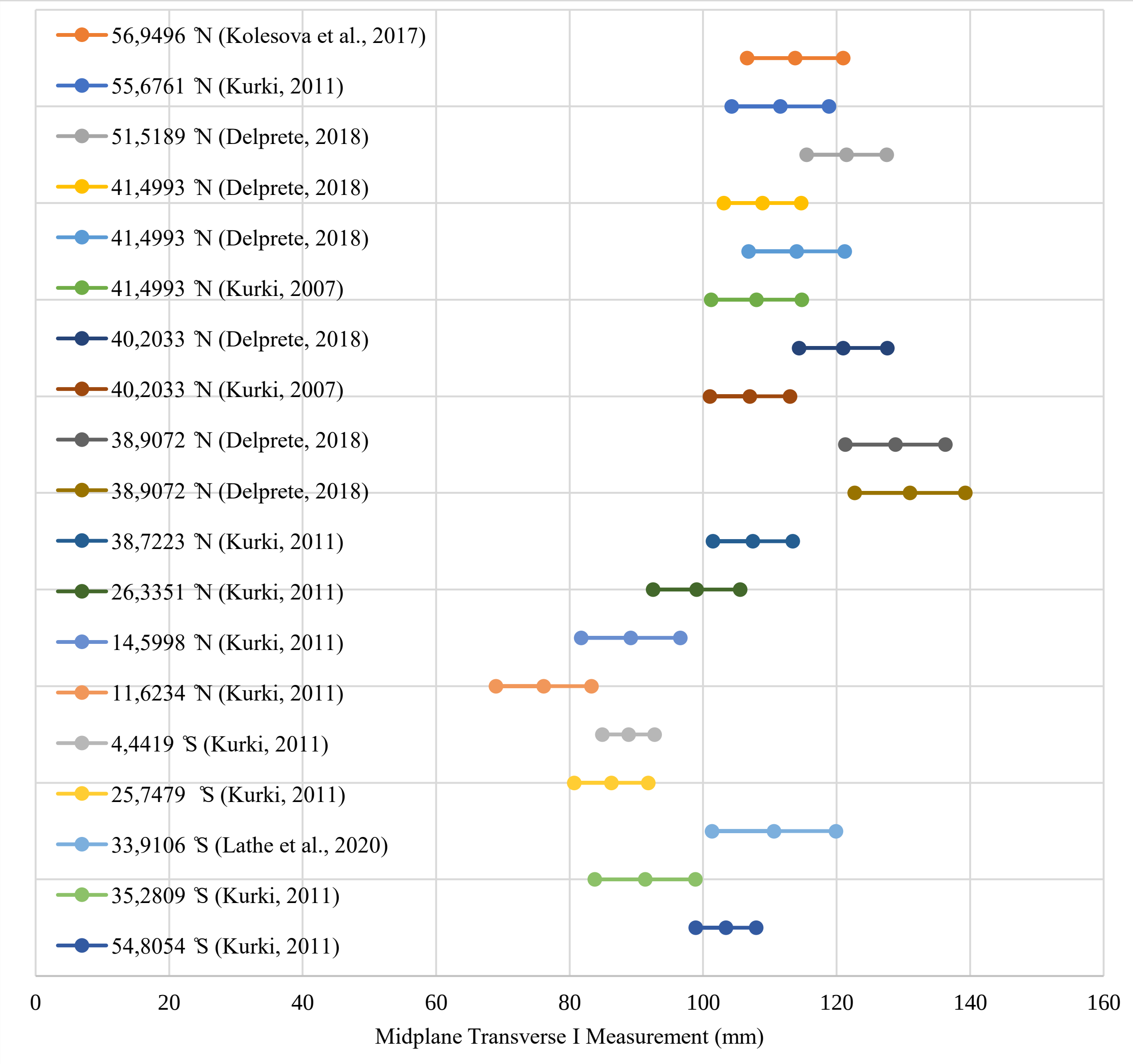


***Figure 4.4*** *Available world-wide data for midplane transverse I measurement of pelvis summarised by latitude of studied population (and authors)*

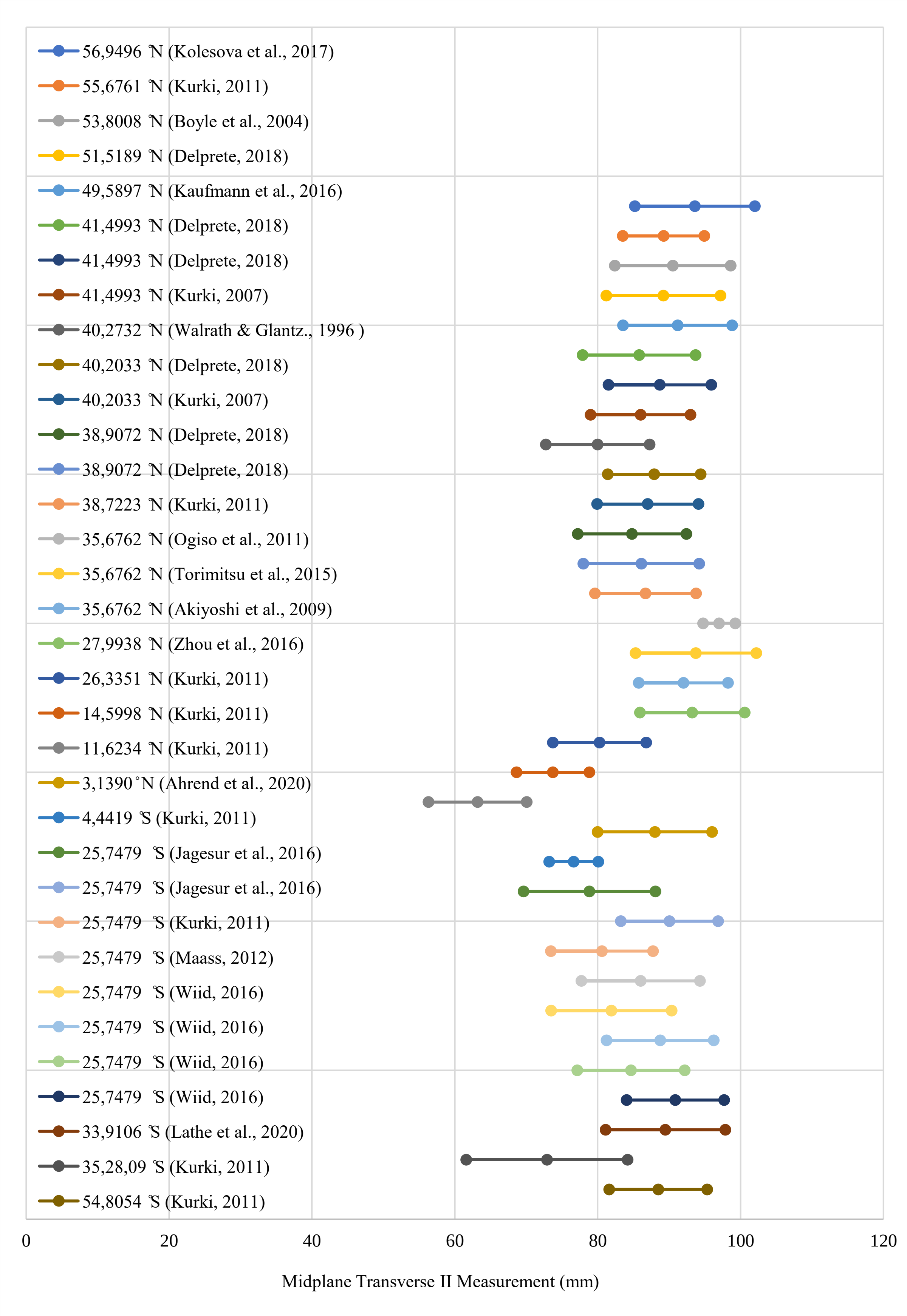


***Figure 4.5*** *Available world-wide data for midplane transverse II measurement of pelvis summarised by latitude of studied population (and authors).*

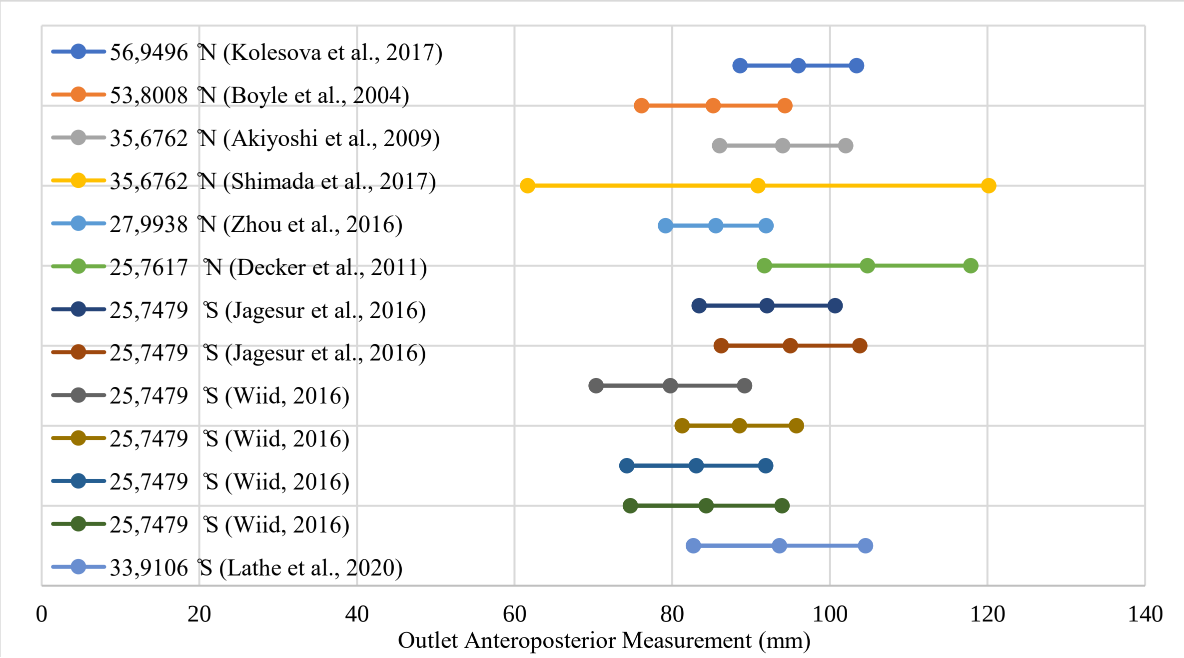


***Figure 4.6*** *Available world-wide data for outlet anteroposterior measurement of pelvis summarised by latitude of studied population (and authors).*

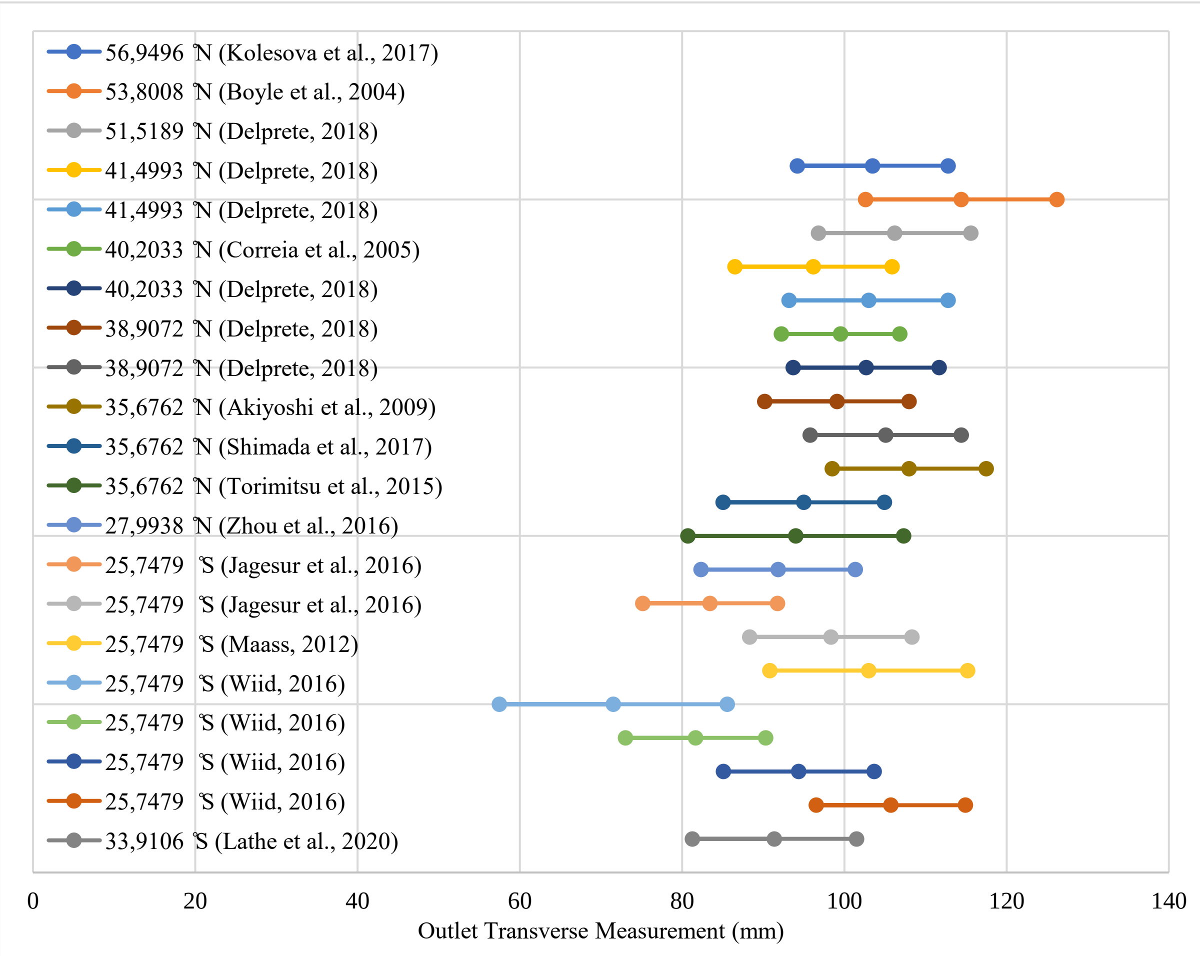


*Figure 4.7 Available world-wide data for outlet transverse measurement of pelvis summarised by latitude of studied population (and authors).*

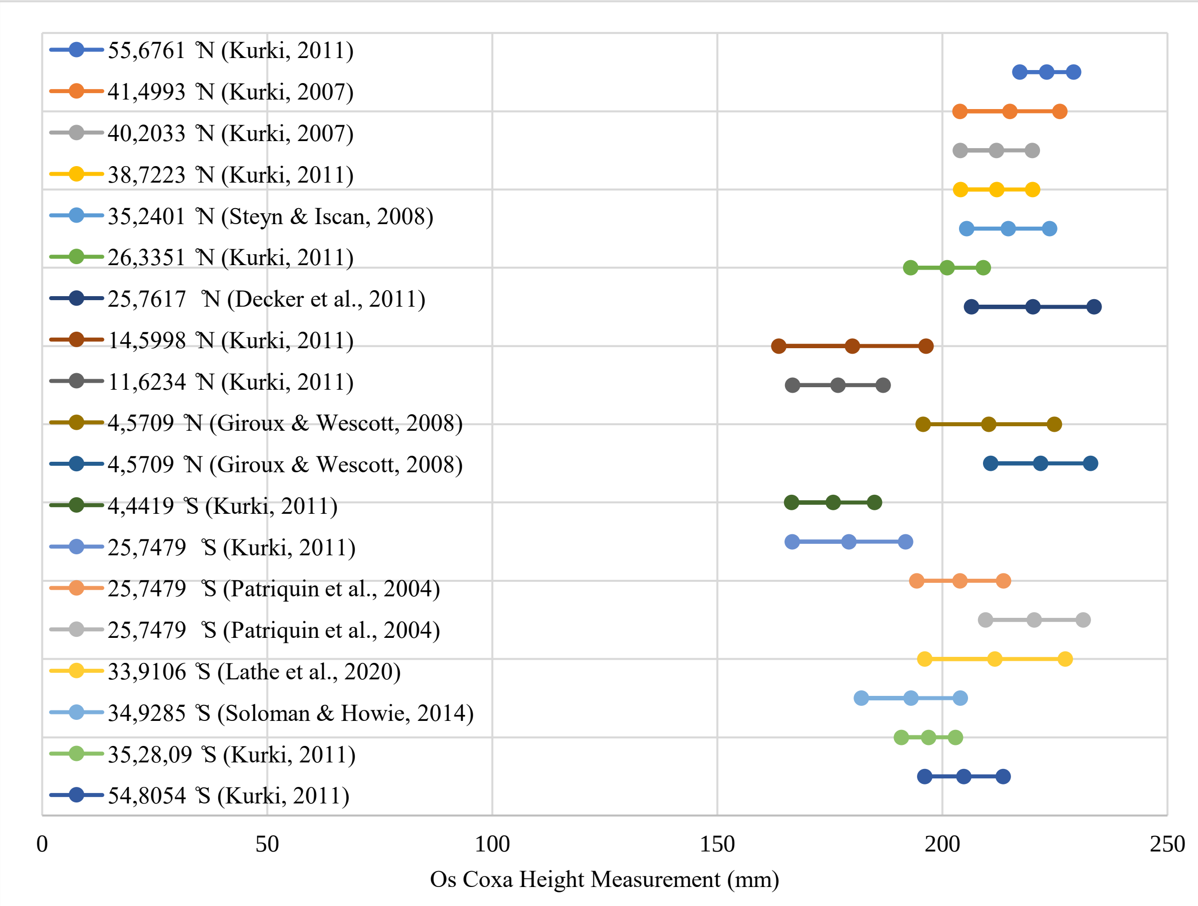


***Figure 4.8** Available world-wide data for os coxa height summarised by latitude of studied population (and authors).*

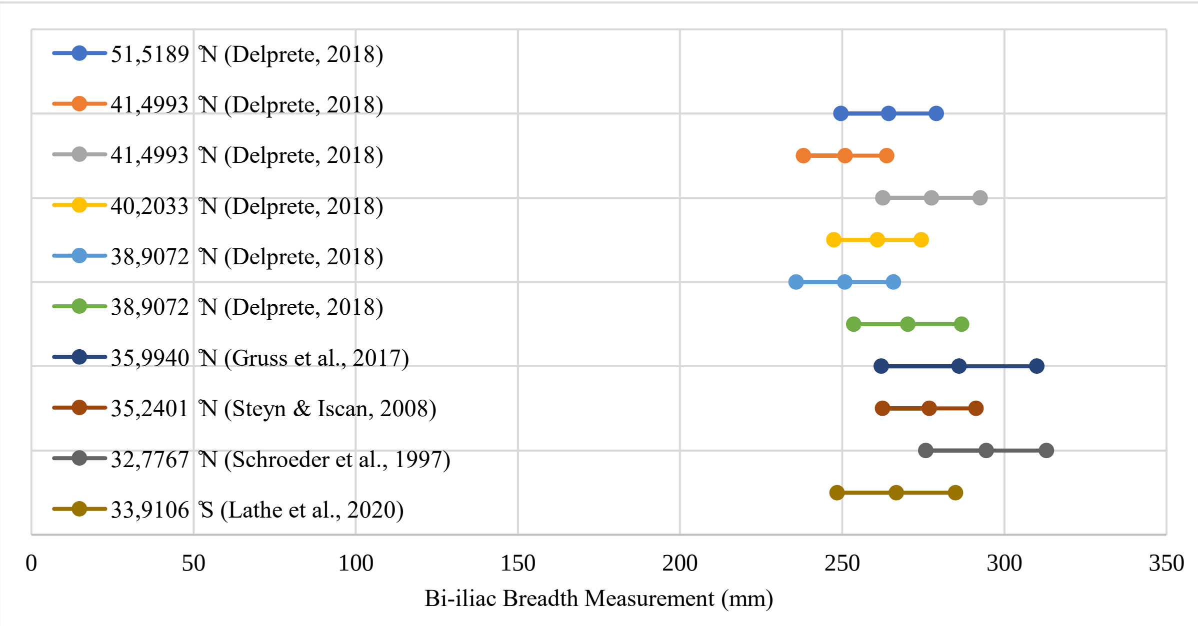


***Figure 4.9** Available world-wide data for bi-iliac breadth of pelvis summarised by latitude of studied population (and authors).*

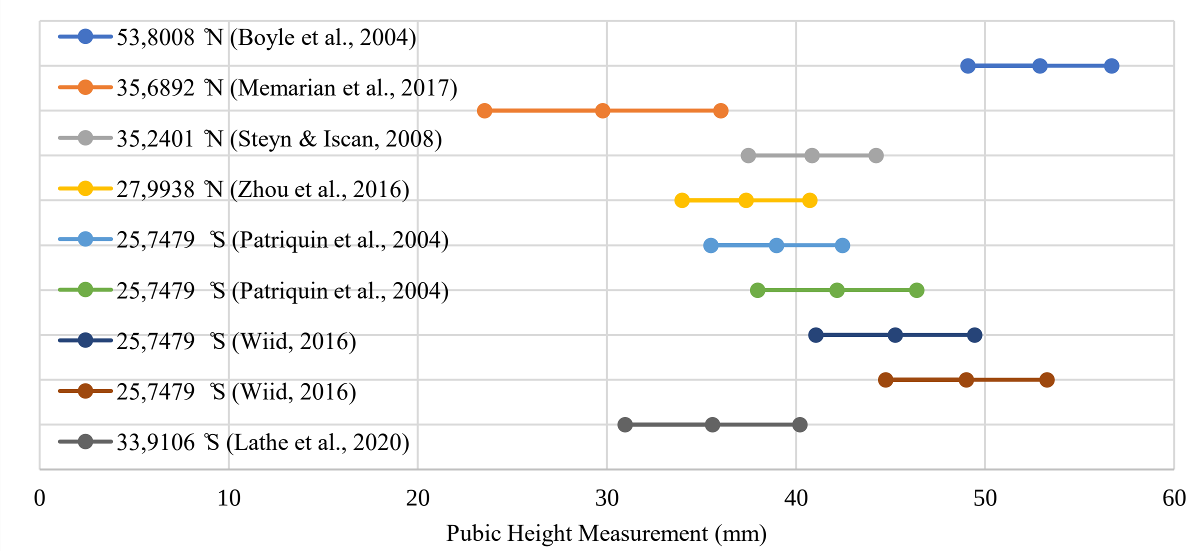


***Figure 4.10** Available world-wide data for pubic height summarised by latitude of studied population (and authors).*

## 4.2 CLINICAL INVESTIGATION

### 4.2.1 Morbidity

The surgical complications of 34 patients who had previously been studied were obtained, and pelvic measurements were taken from the CT scans of 29 these patients (5 patients meeting the exclusion criteria). Complications were present in 13 of the 34 patients (38%). The mean age (years) of the whole sample (n = 34) was 60.05 (δ = 12.09), while that of the patients who experienced surgical complications was 63.08 (δ = 10.32), and those that did not was 58.19 (δ = 12.94) (Table 4.4-4.5). Similar values were found for the 29 patients whose pelvic measurements were taken (Table 4.4-4.5).

***Table 4.5** Age distribution of the sample.*

| | *Age* | | | |
|---|---|---|---|---|
| | *Mean* | *SD* | *Minimum* | *Maximum* |
| Whole sample (n=34) | 60,06 | 12,09 | 33 | 83 |
| Measured sample (n=29) | 60,07 | 12,51 | 33 | 83 |

***Table 4.6*** *Surgical complications observed in the sample.*

| | All 34 patients | | | Measured 29 patients | | |
|---|---|---|---|---|---|---|
| | Patient rate (%) | Mean age | SD | Patient rate (%) | Mean age | SD |
| No surgical complication | 61,76 | 58,19 | 12,94 | 55,17 | 57,63 | 13,88 |
| Surgical complication present | 38,24 | 63,08 | 10,32 | 44,83 | 63,08 | 10,32 |
| Minor complication (CD I+II) | 20,59 | 69,00 | 8,08 | 24,14 | 69,00 | 8,08 |
| Major complication (CD III+IV) | 14,71 | 55,40 | 9,18 | 17,24 | 55,40 | 9,18 |
| Mortality (CD V) | 2,94 | 60,00 | - | 3,45 | 60,00 | - |

The surgical complications observed are summarised in Table 4.6 and Figure 4.11. For the whole sample (n=34), minor complications (CD I+II) occurred in 20,59% (7/34) of patients, major complications (CD III+IV) in 14.71% (5/34), and mortality (CD V) in 2.94% (1/34). For each surgical complication group observed, mean age and pelvic dimensions were calculated (Table 4.7).

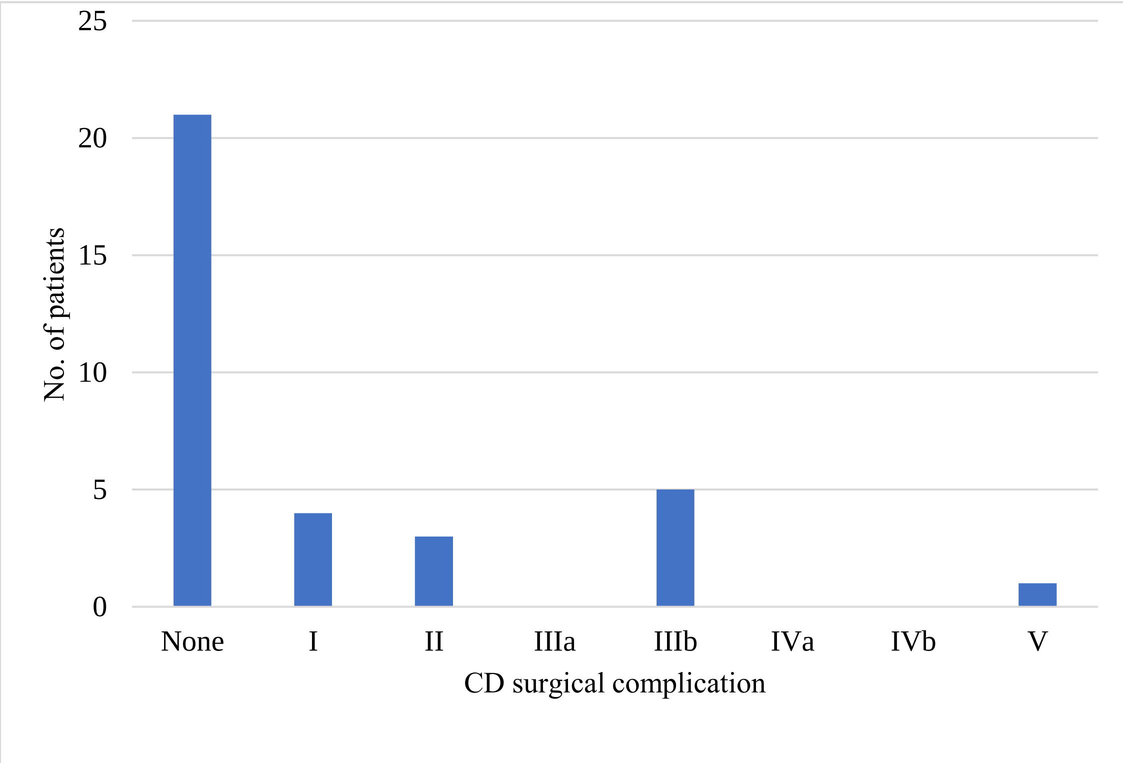


***Figure 4.11*** *Surgical complications observed in the sample (n=34).*

***Table 4.7*** *Mean age and pelvic dimensions for each surgical complication group observed.*

| | | Morbidity | | | | |
|---|---|---|---|---|---|---|
| | | *None* | *I* | *II* | *IIIb* | *V* |
| Age | Mean | 56.50 | 70.75 | 66.67 | 52.80 | 60.00 |
| | SD | 13.89 | 9.11 | 7.57 | 6.06 | . |
| Pubic length | Mean | 117.29 | 110.18 | 117.83 | 120.12 | 112.20 |
| | SD | 7.06 | 4.33 | 6.49 | 12.67 | . |
| Pubic width | Mean | 24.21 | 24.53 | 24.63 | 22.36 | 23.10 |
| | SD | 3.79 | 2.44 | 2.18 | 2.00 | . |
| Pubic height | Mean | 35.80 | 37.88 | 34.40 | 36.44 | 30.10 |
| | SD | 4.91 | 3.52 | 2.78 | 5.36 | . |
| Ischial length | Mean | 108.58 | 105.23 | 111.87 | 109.28 | 109.30 |
| | SD | 8.93 | 7.75 | 9.71 | 6.70 | . |
| Acetabulum diameter | Mean | 52.40 | 48.95 | 50.60 | 51.28 | 50.40 |
| | SD | 4.60 | 3.18 | 4.46 | 3.64 | . |
| Obturator foramen height | Mean | 56.72 | 55.53 | 56.40 | 58.40 | 50.10 |
| | SD | 4.07 | 2.66 | 1.39 | 7.09 | . |
| Obturator foramen width | Mean | 34.40 | 31.23 | 35.70 | 36.06 | 28.10 |
| | SD | 3.53 | 1.77 | 1.08 | 7.01 | . |
| Greater sciatic notch width | Mean | 47.47 | 40.10 | 48.80 | 48.26 | 47.10 |
| | SD | 5.45 | 4.61 | 8.92 | 7.57 | . |
| Iliac breadth | Mean | 161.74 | 151.27 | 161.33 | 162.68 | 148.30 |
| | SD | 12.28 | 13.35 | 2.90 | 8.49 | . |
| Bi-iliac breadth | Mean | 276.54 | 261.08 | 274.73 | 272.46 | 280.70 |
| | SD | 21.26 | 22.49 | 13.50 | 23.71 | . |
| Os coxa height | Mean | 217.46 | 208.85 | 213.03 | 217.06 | 206.80 |
| | SD | 15.71 | 10.58 | 24.99 | 17.91 | . |
| Inlet anteroposterior | Mean | 112.48 | 90.65 | 108.77 | 114.16 | 111.50 |
| | SD | 10.70 | 11.11 | 13.63 | 10.00 | . |
| Inlet transverse | Mean | 123.56 | 117.00 | 120.10 | 121.20 | 115.30 |
| | SD | 10.43 | 8.60 | 1.15 | 13.34 | . |
| Midplane anteroposterior I | Mean | 121.41 | 110.28 | 123.40 | 125.86 | 113.10 |
| | SD | 13.92 | 7.29 | 9.70 | 19.56 | . |
| Midplane transverse I | Mean | 110.89 | 104.20 | 114.43 | 113.60 | 108.60 |
| | SD | 14.74 | 10.55 | 7.42 | 12.39 | . |
| Midplane anteroposterior II | Mean | 123.17 | 115.65 | 127.53 | 122.14 | 121.60 |
| | SD | 7.47 | 10.07 | 9.41 | 14.24 | . |
| Midplane transverse II | Mean | 89.14 | 82.48 | 94.70 | 89.80 | 89.50 |
| | SD | 7.70 | 3.63 | 10.86 | 13.22 | . |
| Outlet anteroposterior | Mean | 95.86 | 86.85 | 94.40 | 91.60 | 95.40 |
| | SD | 8.59 | 6.25 | 9.37 | 17.55 | . |
| Outlet transverse | Mean | 88.39 | 82.75 | 92.60 | 88.06 | 96.00 |
| | SD | 11.60 | 10.28 | 12.59 | 6.49 | . |

The mean age and value for each pelvic dimension was calculated for the no surgical complication and different CD complication groups (Table 4.6). Furthermore, a one-way ANOVA with a post hoc Bonferroni test was performed to test if significant difference occur in pelvic canal measurements between the observed surgical complications groups and no complications group, as well as between the complication groups (Appendix B).

A significant difference was found in the inlet anteroposterior measurement between no surgical complications and complication type I, as well as between complications type I and IIIb (Figure 4.12). On average, the inlet anteroposterior diameter is 21.83mm shorter in individuals who experience complication type I compared with those who experience none. This measurement was found to be 23.51mm longer in those with a complication with type IIIb than type I.

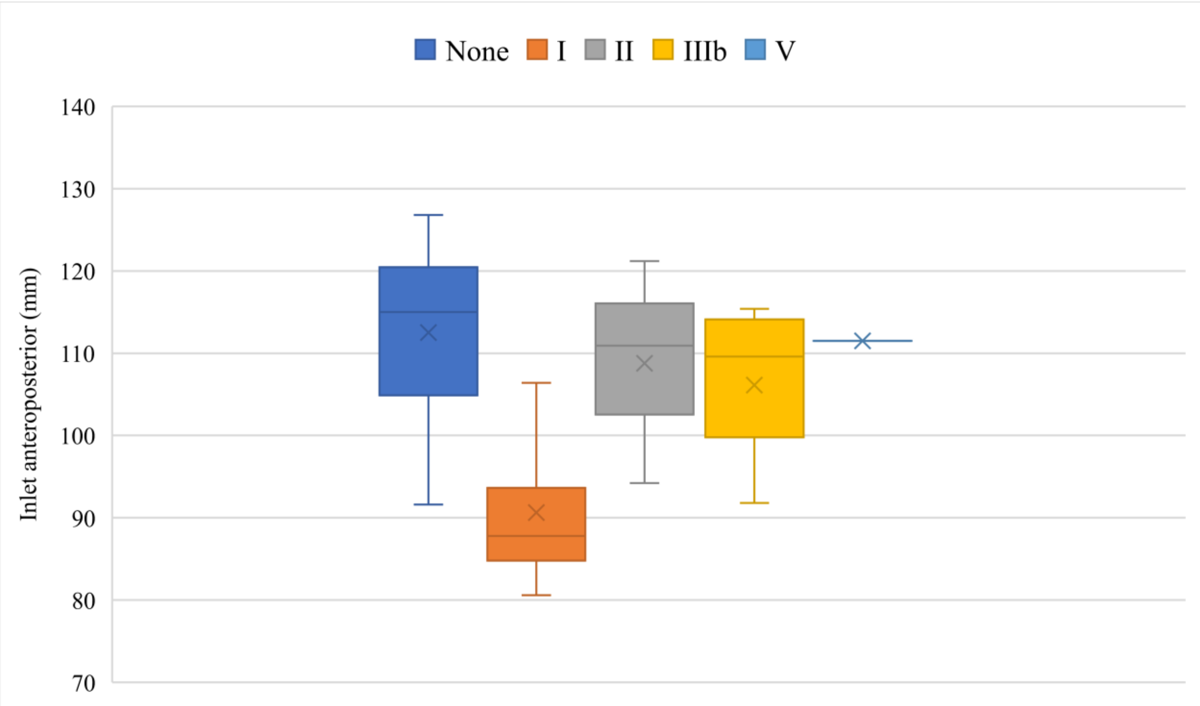


***Figure 4.12*** *Inlet anteroposterior measurement compared with surgical complication groups.*

# CHAPTER 5: DISCUSSION AND CONCLUSION

## 5.1 DISCUSSION

The study sought to define two main aims. The first was to measure the dimensions of the bony pelvis in males from the Western Cape who have undergone colorectal cancer surgery and the second was to determine if an association exists between pelvic dimensions and operative morbidity. The researcher set about to obtain pelvimetric measurements from CT scans of colorectal cancer surgery patients using a 3D reconstruction of the pelvis on PISP software and compared the findings to those from other ecogeographical regions. The pelvimetric findings were thereafter correlated to morbidity documented in patients.

### 5.1.1 Anatomical investigation

The human pelvis is an important anatomical structure, contributing to many essential biological processes, including parturition, bipedal locomotion, and thermoregulation. The importance of such processes in reproductive success and survival of the human species causes them to be under strong natural selection pressure (Gruss & Schmitt, 2015; Betti, 2017). Males and females are known to display differing pelves, assumedly due to differing locomotory and obstetrical functional roles, with males exhibiting narrower pelvic dimensions than females (Kurki, 2013b).

The most critical evolutionary pressure believed to act on the bony pelvis is the need for pelvic shape to allow for delivery of an encephalised neonate without harm to the mother; however, this pressure acts solely on females (Tague & Lovejoy, 1986; Wells *et al*, 2012; Kurki, 2013a; Gruss & Schmitt, 2015). Energetically efficient bipedal locomotion with minimal risk of injury requires a robust pelvic shape that minimises muscle load while maximising muscle lever arms (Lovejoy, 1988; Gruss & Schmitt, 2015). Furthermore, thermoregulation of the body is affected by pelvic width and depth, which affects body proportions and surface area-to-mass ratio of the body, thereby influencing heat loss through body surface (Ruff, 1991, 1994, 2010; Gruss & Schmitt, 2015). All of these factors warrant differing pelvic morphology and demands to be met. Natural selection has favoured compromises between these sometime contradictory pressures (Kurki, 2011; Wells *et al.*, 2012; Gruss & Schmitt, 2015).

#### 5.1.1.1 Pelvimetry of studied population

The pelvimetry of our cohort, South African males from the WC who have undergone colorectal cancer surgery (n=158), was investigated and the results can be found in Table 4.2. The most variable measurement of the single os coxa, or hip bone was found to be os coxa height ($\overline{x}$ = 211.69mm; $\delta$ = 15.59), extending from the most superior point of the iliac crest to the most inferior point of ischial tuberosity (Figure 3.1.B). The least variable os coxa measurement was pubic width ($\bar{x}$ = 23.77mm; δ = 3.20), extending from the most inferior point on the face of the pubic symphysis, horizontally to the medial aspect of obturator foramen on the dorsal aspect of the bone (Figure 3.1.E). Results from the entire pelvic girdle ring showed that the most variable measurement was bi-iliac breadth ($\bar{x}$ = 266.67mm; δ = 18.25), measured as the maximum distance between the lateral most projections of the iliac crests (Figure 3.1.D), while the least variable was midplane transverse II or bispinous measurement ($\bar{x}$ = 89.47mm; δ = 8.38), measured as the maximum distance between the lateral most projections of the iliac crests (Figure 3.1.E). When comparing the standard deviations of the unilateral os coxa measurements with the pelvic girdle measurements, one can see that the pelvic girdle measurements (Range of δ = 8.38-18.25) as well as os coxa height (δ = 15.59) and iliac breadth (δ = 12.75) are more variable than the remaining os coxa measurements (Range of δ = 3.20-7.07) (Table 4.2).

Levels of intraspecific variation, or variation within a population, depend on interactions between plasticity and constraints. Plasticity refers to an organism’s ability to adapt to stimuli during growth, while constraints are limitations on morphology due to genetics, development, and natural selection. Thus, greater plasticity allows greater intraspecific variability, and conversely, greater constraints reduces it (Grabowski, 2013; Gruss & Schmitt, 2015). Perhaps the measurements found to be more variable in our population have greater plasticity, which includes the pelvic girdle measurements, os coxa height, and iliac breadth (Table 4.2). Conversely, the measurements found to be less variable may be under greater constraint, including the unilateral os coxa measurements, with the exception of the two previously mentioned. Kurki (2013a) explains that, as bony pelvic canal dimensions vary between populations, the relationship between constraints affecting phenotype may be different between populations exhibiting differing body proportions and sizes.

Previously, it has been believed that the male pelvis is more variable than the female pelvis as the latter is under stricter selective pressure due to obstetrical requirements (Kurki, 2013a, 2013b; Warrener *et al.*, 2015). However, Kurki (2013a) and Betti *et al.* (2013) both displayed that there is a lack in differences between male and female bony pelvic variability. Kurki (2013a) found that pelvic canal measurements (or the true pelvis) exhibit higher variability than non-canal measurements (false pelvis) in both sexes, while Betti *et al.* (2013) found the opposite to be true. Kurki (2013a) further explains that the discrepancy between these results likely lies in the fact that her study examined variation of linear dimensions while Betti *et al.*

(2013) examined shape variation in a 3D space using landmark data. Additionally, Kurki (2013a) included the whole articulated pelvis, while Betti *et al*. (2013) considered landmarks representing the shape of the os coxa alone. This may show that canal variation increases by variation in sacral positioning relative to the os coxa (Betti *et al.*, 2013; Kurki, 2013a). Our data is more comparable with Kurki (2013a) as we similarly considered the pelvic girdle as a whole using linear dimensions, and also supports the idea above. Measurements of the true pelvis that are unaffected by sacral positioning displayed lower variability (Range of $\delta$ = 3.25-7.07) than the dimensions measured in the canal that are (Range of $\delta$ = 8.38-12.40). The majority of the measurements taken in this study are from the true pelvis, making it difficult to compare variability between the true and false pelvis. Two false pelvis measurements were investigated, including bi-iliac ($\delta$ = 15.59) and iliac breadth ($\delta$ = 12.75), however, both measurements were similarly variable to those of the true pelvis canal.

5.1.1.2 Intraobserver error

Intraobserver error was investigated to test repeatability of the pelvimetry measurements. A paired samples t-test was performed to investigate the mean differences between 10% of the measurements that were repeated by the primary investigator (Table 4.2). The mean difference (MD) between observations for all measurements, except outlet transverse diameter, were found to not be significantly different ($p > 0.05$), and thus the null hypothesis could be accepted. This shows that these measurements have good intraobserver agreement and can be said to be repeatable.

The MD between observations for outlet transverse diameter, at 1.36mm, was found to be statistically significant ($p = 0.04$). This may be attributed to the bony landmarks demarking this measurement being more difficult to distinguish than the landmarks for the other measurements. Outlet transverse was measured as the maximum distance between the two internal points of ischial tuberosities. Error may have occurred in distinguishing the exact point where this tuberosity transitions from the internal aspect to the inferior (sit bone) portion. Although the MD was found to be significant, it is not a large difference, with a p-value very close to 0.05.

5.1.1.3 Interobserver error

Interobserver error was investigated to test reproducibility of the pelvimetry measurements. Similarly, to above, 10% of the measurements were repeated, this time by an independent researcher, to investigate the mean differences between them by performing a paired samples t-test (Table 4.3). The MD between observations for the following measurements were not found to be statistically significant ($p > 0.05$): pubic width; ischial length; iliac breadth; bi-iliac breadth; inlet transverse diameter; and outlet transverse diameter. These results show good reproducibility in these measurements.

Conversely, statistically significant differences ($p \leq 0.05$) were found between observations for the following measurements: pubic length ($p = 0.05$); pubic height ($p = 0.00$); acetabulum diameter ($p = 0.00$); obturator foramen height ($p = 0.00$); obturator foramen width ($p = 0.00$); os coxa height ($p = 0.00$); inlet anteroposterior diameter ($p = 0.00$); midplane anteroposterior I diameter ($p = 0.00$); midplane transverse I diameter ($p = 0.01$); midplane anteroposterior II diameter ($p = 0.01$); midplane transverse II diameter ($p = 0.01$); and outlet anteroposterior diameter ($p = 0.00$). This could be due to various reasons. Again, there may have been difficulty in distinguishing the bony landmarks which demarcate each measurement, however, what may be worth noting is that there was a large time gap between when the primary investigator explained the bony landmarks and measurements to the independent researcher, and when the independent researcher was able to perform the pelvimetry.

Pubic length was measured from the superior border of the acetabulum at the centre of origin of the iliac blade, to the most superior and medial point on the pubic crest. The latter landmark is a prominent bony projection; however, the former is a less pronounced landmark which is demarcated as a small ridge on the superior border of the acetabulum. Pubic height extends between the most superior to the most inferior point on the pubic symphysis, which undergoes changes in texture and appearance during aging. The borders of the pubic symphysis become clearer during aging as the symphyseal rim develops and eventually completely encircles the symphyseal face. With further aging, this rim begins to then erode, making the borders more difficult to distinguish. Thus, the landmarks for pubic height vary in distinguishability with age (Brooks & Suchey, 1990; Jones *et al.*, 2018). Acetabulum diameter is the length from the middle of the ridge on the superior border to the inferior border. The entire acetabular socket could not be visualised which may have affected distinguishing the landmarks. The scans came from living patients, thus the femur was segmented out of the image as close as possible to the acetabulum without cutting away any of the pelves.

Obturator foramen height was measured as maximum height between the inferior most point within the foramen to the most superior point at the superior pubic ramus, and obturator foramen width is dependent on this measurement, perpendicular to the height, from the posterior to anterior borders of the foramen. These measurements involve some subjectivity as the landmarks are not clear demarcated bony points, rather approximated superior, inferior, anterior, and posterior points on an irregular diamond/oval shape. Os coxa height extends from the most superior point on the iliac crest to the most inferior point of the ischial tuberosity. Finding these superior- and inferior-most points involves exploring the lateral view of the os coxa at different angles due to the irregular nature of this bone and the outward angle and projection of the iliac blade. Visualising both the superior- and inferior-most points at the same time requires viewing the os coxa from and infero-lateral angle and finding this precise view may have influenced repeatability of this measurement.

All anteroposterior measurements of the pelvic canal, including inlet, midplane I, midplane II, and outlet were taken from the same view. The right half of the pelvic girdle is segmented away from the midline to view the left pubic symphyseal face, medial left os coxa, and the lateral view of the sacrum sectioned through the midline in the sagittal plane (Figure 3.1.C). The sagittal midline of the sacrum is estimated when segmenting away the right half of the pelvic girdle and this may have affected differences between observers. Each anteroposterior measurement extends from varying positions on the posterior surface of the pubic symphysis to different midline positions alone the sacrum and coccyx. Sacral and coccygeal landmark are pronounced as they included the top of the sacrum, the tip of the coccyx, and the separation between sacral segments which were demarcated by remains of intervertebral discs where the sacral vertebrae are fused. However, pubic landmarks were less prominent and did not have clear bony features.

#### 5.1.1.2 Global trends and variation of pelvic dimensions

The effects of ecogeography on the human body have long been discussed (Schreider, 1950, 1964, 1975; Ruff, 1991, 1994; Gruss & Schmitt, 2015; Betti, 2017; Betti & Manica, 2018) Population means in phenotypes are believed to be structured along a latitude gradient of optimal physical states (Roseman & Auerbach, 2015). In theory, if climate, and by extension latitude, affect the size of the bony pelvis due to thermoregulatory needs of the body, the following would be expected: populations from lower latitudes, closer to the equator, where the climate is hotter, will exhibit narrow deep pelves as these factors allow for better thermoregulation. Northern and southern distance from the equator should see a transition of the pelvis to be wider and shallower as latitude increases and temperatures decrease (Hanna & Brown, 1983; Mayr, 1956; Ruff, 1991, 1994, 2010; Schreider, 1950, 1964, 1975).

Latitude is horizontal or transverse bands that run parallel to the equator which represent an angle from 0˚at the equator to 90˚ North (N) or South (S) at either pole. Latitude is used in conjunction with longitude to name locations on the earth's surface. Climate is at its hottest at the equator and decreases as latitude increases. The latitude of Tygerberg Hospital was chosen to represent our population as the hospital serves the public in surrounding residing areas and was thus estimated as the centroid for this population. It is situated at 33,9106˚S of the equator and is roughly one-third of the distance between the equator and South pole.

The findings of our study compared to other ecogeographical regions are discussed in the following section.

The forest plots revealed that our population displays a relatively narrow true pelvis in the transverse plane. More specifically, the true pelvis was found to be narrow in the transverse plane at the inlet, outlet, and midplane transverse I, or bi-acetabular levels. Conversely, the opposite was found for the true pelvis in the anteroposterior plane, specifically at the levels of the inlet, midplane II, as well as the outlet, although to a lesser extent. Pubic height of this population was found to be slightly short, os coxa height slightly tall, and bi-iliac breadth along with midplane transverse II were average compared to global data.

When comparing our results for the inlet anteroposterior measurement (Figure 4.1) with those from similar latitudes, eight populations display a smaller diameter, while seven were larger and two display similar diameters. Latitudes higher than us showed nine populations with a smaller diameter, one with a larger, and three with similar values to ours. Lower latitudes show three populations with a smaller and one with a similar diameter to our population (Boyle *et al.*, 2005; Correia, Balseiro & De Areia, 2005; Kurki, 2007, 2011; Steyn & Iscan, 2008; Akiyoshi *et al.*, 2009; Decker, Davy-Jow, Ford & Hilbelink, 2011; Ogiso & Yamaguchi, 2011; Maass, 2012; Jagesur, Wiid, Pretorius, Bosman & Oettlé, 2016; Wiid, 2016; Zhou *et al.*, 2016; Kolesova, & Vetra, 2017; Shimada, Tsuruta, Hasegawa & Okabayashi, 2018; DelPrete, 2019; Ahrend, Noser, Shanmugam, Burr, Kamer, Kamarul, Hügli, Nagy, Richards & Gueorguiev-Rüegg, 2020;). This shows that the studied population exhibits a relatively large inlet anteroposterior diameter compared to higher and lower latitudes.

Inlet transverse diameter (Figure 4.2) of our population appears average compared to populations from similar latitudes, with seven displaying a smaller, two displaying a similar, and seven displaying a larger diameter. The three populations found at a lower latitude exhibit a smaller diameter, while a majority of populations at higher latitudes displayed a larger value (eight larger, three smaller, and four similar), thereby seemingly following the expected size pattern according to climate (Walrath & Glantz, 1996; Schroeder, Schmidtke & Bidez, 1997; Kurki, 2007, 2011; Steyn & Iscan, 2008; Decker *et al.*, 2011; Ogiso & Yamaguchi, 2011; Maass, 2012; Jagesur *et al.*, 2016; Kolesova *et al.*, 2017; Shimada *et al.*, 2018; DelPrete, 2019; Torimitsu, Makino, Saitoh, Sakuma, Ishii, Yajima, Inokuchi, Motomura, Chiba, Yamaguchi, Hashimoto, Hoshioka & Iwase, 2015; Wiid, 2016).

The midplane anteroposterior II measurement (Figure 4.3) of our population appears to be large compared to other regions. This measurement is slightly larger than populations from a similar latitude; four populations display smaller values, one displays a similar one, and two display a larger value. Both lower and higher latitudes show a smaller diameter than this population. All lower latitude populations exhibit lower values, while 10 populations from higher latitudes exhibit lower values and three display similar ones (Correia *et al.*, 2005; DelPrete, 2019; Kolesova *et al.*, 2017; Kurki, 2007, 2011; Wiid, 2016). These results do not follow any ecogeographical pattern.

Midplane transverse I, or bi-acetabula, measurement (Figure 4.4) of our population is relatively narrow compared to warmer regions. Higher latitudes show six populations with a larger diameter, three with a similar, and three with a smaller measurement. Lower and similar latitude populations all exhibited smaller diameters (Kurki, 2007, 2011; Kolesova *et al.*, 2017; DelPrete, 2019). These results display a weak ecogeographical pattern.

Midplane transverse II, or bi-spinous dimension (Figure 4.5) of our population does not vary much between ecogeographical regions compared to other measurements, and no pattern was found. We displayed a slightly larger midplane transverse II than similar and lower latitudes while appearing average compared to higher latitudes. Lower latitudes show three populations with a smaller and one with a similar value to this population, while similar latitudes show seven with a smaller, three with a similar, and four with a larger value. Higher latitudes largely displayed similar values to the current population (11 populations with similar values, three with smaller, and one with larger values) (Walrath & Glantz, 1996; Boyle *et al.*, 2005; Kurki, 2007, 2011; Akiyoshi *et al.*, 2009; Ogiso & Yamaguchi, 2011; Maass, 2012; Torimitsu *et al.*, 2015; Wiid, 2016; Zhou *et al.*, 2016; Jagesur *et al.*, 2016; Kaufmann, Lauscher, Gröne, Zur Hausen, Kreis, Hamm & Niehues, 2017; Kolesova *et al.*, 2017; DelPrete, 2019; Ahrend *et al.*, 2020;).

When comparing the outlet anteroposterior diameter (Figure 4.6) of our population with other published data, most studies meeting the necessary criteria were from a similar latitude. Similar latitudes to us showed six populations with a smaller diameter, three with a similar, and one with a larger mean. No studies were found from lower latitudes, but two were found with a higher latitude, of which one showed a larger and one a smaller diameter (Boyle *et al.*, 2005; Akiyoshi *et al.*, 2009; Decker, Davy-Jow, Ford & Hilbelink, 2011; Jagesur *et al.*, 2016; Wiid, 2016; Zhou *et al.*, 2016; Kolesova *et al.*, 2017; Shimada *et al.*, 2018). This shows that our population exhibits a slightly large outlet anteroposterior diameter compared to similar regions, an average diameter compared to higher latitudes, and a comment cannot be made regarding lower latitudes. No ecogeographical pattern was found.

Our outlet transverse diameter (Figure 4.7) was similar to populations from similar latitudes and narrow compared to those from higher latitudes, however, no data was found from lower latitudes. Similar latitudes showed four populations exhibiting a similar diameter, three a smaller, and four a larger value than ours. The nine populations found at a higher latitude all exhibited a wider outlet transverse measurement (Boyle *et al.*, 2005; Correia *et al.*, 2005; Akiyoshi *et al.*, 2009; Maass, 2012; Jagesur *et al.*, 2016; Torimitsu *et al.*, 2015; Wiid, 2016; Zhou *et al.*, 2016; Kolesova *et al.*, 2017; Shimada *et al.*, 2018; DelPrete, 2019;). These values appear to follow the expected ecogeographical pattern; however, it is difficult to say without values from lower latitudes with which to compare.

The pubic height (Figure 4.8) appears short in the studied population compared to all other studies found with comparable data. Five populations from similar latitudes exhibited larger values for pubic height, while one was similar and one was smaller. The one population found at a higher latitude showed a taller pubic height than the studied population. No studies from a lower latitude were found and an ecogeographical pattern could not be identified (Boyle *et al.*, 2005; Patriquin, Steyn & Loth, 2005; Steyn & Iscan, 2008; Wiid, 2016; Zhou *et al.*, 2016; Memarian, Aghakhani, Mehrpisheh & Fares, 2017).

Our population displayed an average os coxa height (Figure 4.9) compared to higher latitudes; however, it appears to be slightly tall compared to similar and lower latitudes. Similar latitudes showed two populations with a similar height, while five were shorter and two were taller. Lower latitudes displayed one population with a similar height, three with a shorter, and one with a taller, while higher latitudes show two with a similar, one with a shorter, and one with a taller height (Patriquin *et al.*, 2005; Giroux & Wescott, 2008; Kurki, 2007, 2011; Steyn &

Iscan, 2008; Decker *et al.*, 2011; Solomon, Howie & Henneberg, 2014). Values from lower latitudes appear to follow expected ecogeographical patterns, however, similar and higher latitudes do not.

Bi-iliac breadth (Figure 4.10) of our population is slightly narrow compared to similar regions, and average compared to higher latitudes; no data was found from lower latitudes. Similar latitudes showed one population with a similar bi-iliac breadth to the studied population, while three were wider and one was narrower. Higher latitudes displayed two populations exhibiting similar widths, while one was wider and one narrower (Schroeder *et al.*, 1997; Steyn & Iscan, 2008; Gruss, Gruss, Schmitt & Carolina, 2017; DelPrete, 2019;). No ecogeographical pattern was evident.

When considering all of the forest plots as a whole, the pelvic dimensions did not follow an obvious ecogeographical pattern, however, some data did hint towards such a pattern. Pelvic dimensions appear to decrease as one looks closer to the equator, however, the amount of available data found from low latitudes is significantly less than the data found at higher latitudes. Pelvic dimensions of populations from higher latitudes rarely followed the expected ecogeographical pattern. Interestingly, the measurements that did appear to follow the expected ecogeographical patterns in both high and low latitudes were the transverse planes found to be narrow in the studied population (inlet, midplane I, and outlet).

It is generally reported that individuals from higher latitudes tend to have relatively stockier and larger bodies with shorter limbs, while those from lower latitudes have smaller and longer bodies with elongated limbs. Some authors focus on bi-iliac breadth and note that high latitude populations display a wider bi-iliac breadth than lower ones (Schreider, 1975; Ruff, 1994; Kurki, 2013a; Betti, 2017). Our population, at a relatively low latitude, was not found to have a particularly narrow bi-iliac breadth compared to higher latitudes, however, comparable data was lacking compared to canal measurements. Others focus on canal measurements, and Kurki (2013a) reported that populations from lower latitudes tend to exhibit narrower transverse midplane and outlet dimensions, accompanied by an expansion in the anteroposterior plane. Our results conquer with these findings, although the same was found to be true at the inlet.

Thus, the dimensions of the male bony pelvis WC individuals who underwent colorectal cancer surgery at TH were measured, investigated, and compared to other ecogeographical regions. Measurements of the true pelvis that are not affected by sacral positioning relating to os coxae were found to be less variable than dimensions of the true pelvis that depend on such positioning. Our population was found to exhibit a transversely narrow pelvic canal compared to regions from higher latitudes, which was accompanied by a relative increase in anteroposterior dimensions.

### 5.1.2 Clinical investigation

Rectal cancer represents a healthcare burden that affects South African males more commonly than females. In 2014, it was found to be the fourth most common, accounting for 5.3% of histologically diagnosed cancers in males, and sixth most common, accounting for 4,3% diagnosed in females (National Institute for Communicable Diseases, 2014). Surgical intervention is key in the management of this condition, and since it was introduced by Heald in 1982, the TME has remained the gold standard for mid to low rectal cancer as LR was decreased (Heald *et al.*, 1982; Bennis *et al.*, 2012; Baek *et al.*, 2015; Lacy, Tasende, Delgado, Fernandez-Hevia, Jimenez, De Lacy, Castells, Bravo, Wexner & Heald, 2015). Surgical instruments and techniques for this procedure have improved over time, however it is still associated with risks and morbidity (Bennis *et al.*, 2012; Baek *et al.*, 2015). Main risk factors include large tumour, CRT, and male patients or narrow deep pelvic anatomy (Baek *et al.*, 2015). Some morbidities associated with TME include coloanal anastomotic leak, pelvic abscess, local recurrence, stoma closure, risk of a permanent stoma, perineal bleeding (warranting blood transfusion), infection of the perineal wound, intestinal obstruction, and anorectal dysfunction (Bennis *et al.*, 2012; Delibegovic, 2017; Penna, Hompes, Arnold, Wynn, Austin, Warusavitarne, Moran, Hanna, Mortensen & Tekkis, 2019).

Surgical complications assiociated with TME were investigated in our population and discussion of these results follows.

Surgical complications of 34 male patients who have undergone TME at the Tygerberg Hospital have previously been researched and were obtained (Table 4.4-4.5, Figure 4.11). Complications were present in 38.24% of patients, with a mean age of 63.08. The mean age of the whole sample (60.05) and those that did not experience complications (58.19) was found to be lower. Minor complications (CD I+II) occurred in 20.59% of patients, major complications (CD III+IV) in 14.71%, and mortality (CD V) in 2.94%.

Bennis *et al*. (2012) reported morbidity rate in 456 (306 male) patients who underwent low anterior resection with TME. Mean patient age was 61.4 years. Their results showed complications occurring in 11.18% of patients, with 0% mortality. Minor complications were present in 7.24% and major complications in 3.95%. Lacy *et* al. (2015) investigated 140 (89 male) patients with a mean age of 65.5 who underwent transanal TME. Increased complication rates were present, with 34.3% affected: 24.2% with minor complications; 10% with major complications; and no deaths. Both studies showed a similar mean age of samples to ours; however, morbidity data was more comparable with Lacy *et al*. (2015). In a sample of 60 (38 male) patients who underwent laparoscopic TME, Targarona *et al*. (2008) reported a higher mean patient age than ours (74 years), however morbidity (34%) and mortality (2%) rates were similar. These studies all display pooled results for both males and females, making direct comparisons difficult. Li *et al.* (2017) reported morbidity of 117 male patients who underwent laparoscopic abdominoperineal resection for rectal cancer. This group had a lower mean age (59.0 years) and morbidity rate (22.4%) than our population (Li, Li, Jiang, Qiu, Fy, Tang & Chen, 2017).

### 5.1.3 Relationship between clinical and anatomical factors

Various factors influence the surgical outcome of TME, including patient anatomy, incomplete mesorectal excision, tumour characteristics, surgeon's skills, and high body mass index (BMI) (Targarona *et al.*, 2008; Akiyoshi *et al.*, 2009; Ogiso & Yamaguchi, 2011; Bennis *et al.*, 2012; Wang *et al.*, 2014; zur Hausen *et al.*, 2017). The lower, true pelvis is a spatially limited area where this already technically demanding procedure occurs. Precise dissection of the mesorectum between visceral and parietal pelvic fascia is performed within the pelvic cavity (Akiyoshi *et al.*, 2009; Brown *et al.*, 2004). The male pelvis is naturally narrower than female and it is believed that the male sex is more difficult to perform this procedure on. Male patients have been found to have poorer survival rates in some cases and this is attributed to LR resulting from inadequate surgical excision of the mesorectum as a result of narrow pelvic anatomy causing difficulty in accurately visualising, mobilising, and excision the mesorectum (Salerno *et al.*, 2007; Bennis *et al.*, 2012; zur Hausen *et al.*, 2017). Our anatomical investigation has already found the population to display a relatively narrow pelvic canal in the transverse plane, accompanied by an increase in anteroposterior plane.

The relationship between patient morbidity and pelvic dimensions in our population was investigated and results are discussed in the following section.

Mean values for pelvic dimensions were compared between surgical complication groups using one-way ANOVA with a post hoc Bonferroni test (Appendix B). Significant differences were not found in transverse dimensions of the pelvic canal between patient groups. However, differences were found in the inlet anteroposterior measurement between no surgical complications and complication type I (21.83mm), as well as between complications type I and IIIb (23.51mm) (Figure 4.12).

We investigated the relationships between patient morbidity and pelvic dimensions to assess the difficulty of TME. In colorectal oncologic literature, along with the aforementioned, various other operative, oncologic, and patient factors are investigated for surgical difficulty. Examples include patient age, BMI, status of tumour circumferential margins (CRM), LR, operative time, blood loss, and quality of mesorectum (Akiyoshi *et al.*, 2009; Ogiso & Yamaguchi, 2011; Bennis *et al.*, 2012; Killeen, Banerjee, Vijay, Al-Dabbagh, Francis & Warren, 2012; Wang *et al.*, 2014; Li *et al.*, 2017; zur Hausen *et al.*, 2017; Shimada *et al.*, 2018).

Bennis *et al.* (2012), found the male sex to be an independent risk factor for postoperative complications in low AR with TME; however, pelvic dimensions were not explored. Ogiso *et al*. (2011) reported males to display significantly shorter pelvic inlet and outlet transverse and anteroposterior dimensions, as well as significantly greater pelvic depth than females from patients who underwent laparoscopic AR for rectal cancer. However, although males experienced greater blood loss during the procedure, sex did not significantly affect surgical outcomes. Shimada *et al*. (2018) found inlet transverse diameter to be significantly correlated with operative time in AR of rectal cancer. Furthermore, Zur Hausen *et al*. (2017) found this measurement to be associated with a higher probability of worsened TME quality in low AR for rectal cancer. Worsened TME quality means that the mesorectum was not removed as a smooth “en bloc” structure, and some mesorectum may remain, increasing the risk of LR. Killeen *et al*. (2010) reported an association between pelvic outlet anteroposterior dimension and operative time during laparoscopic TME. Li *et al.* (2017) looked into the factors influencing difficulty of laparoscopic AP resection of ultra-low rectal cancer and, along with other clinical, patient, and oncologic factors, reported bispinous dimension (or midplane transverse II) to be a predictor for operative time. Akiyoshi *et al*. (2009) compared pelvic canal dimensions with operative time as a measure of operative difficult in laparoscopic TME with double stapling technique (DST). Outlet transverse dimension was found to be an independent predictor for operative time.

Clinical investigation showed that patients who experience surgical complications tend to be older, and Li *et al*. (2017) found patient age to be a predictive value for blood loss. However, their results also show that no association exists between patient age and morbidity, and both them and Killeen *et al*. (2017) report no association between age and operative time.

Literature trends show transverse pelvic canal measurements to be related to TME outcomes, with narrower dimensions having a detrimental effect. Conversely, our clinical data shows inlet anteroposterior measurements to be somewhat associated with patient morbidity. The anatomical investigation, however, showed that our populations displays a relatively narrow true pelvis, which may increase difficulty in TME techniques; however, no significant results were yielded when testing the association between transverse pelvic measurements and patient morbidity.

Application of our findings to clinical outcome is difficult to determine, as no relationship between dimensions and surgical complications was found with the available data points. As found through previous research, other operative and oncologic factors influence clinical outcomes, including operative time, blood loss, LR, and quality of mesorectum. Considering these factors would be helpful. The standout findings of the study are the measurements that were found to be narrow in our population compared to ecogeographical regions from higher latitudes. These include transverse diameters of pelvic canal inlet and outlet, as well as biacetabular (midplane transverse I) measurement. Interestingly, these measurements represent the pelvic region that was identified by colorectal surgeons from TH to be the area of the pelvis where TME technique becomes difficult. A narrowing of the transverse pelvic canal may affect the quality of fascial separations in the retropubic space that are crucial during dissection and removal of the entire mesorectum due to poor visibility and decreased space in which to manoeuvre. However, this is unconfirmed by morbidity data as significant results were only yielded in the inlet anteroposterior measurement. Identification of a narrow pelvis prior to surgical intervention may improve preoperative decisions regarding the appropriate approach to the pathology.

Thus, no relationship between pelvic dimensions and surgical complications documented in male patients who have undergone TME at TH were identified.

### 5.1.4 Limitations

The study suffered various limitations. The exclusive selection of males undergoing colorectal surgery for the study may have led to sampling bias within the study sample. Data collection was from a single unit and a single imaging service, thus access to facilities was dependent on the availability of a computer and workload of personnel. The coronavirus disease 2019 (COVID-19) pandemic caused abrupt and unprecedented changes to the world, lifestyle, and economy. The emergence of COVID-19 in South Africa caused an unplanned delay (approximately six months) between when the primary investigator explained the intraobserver measurements and bony landmarks to the independent researcher. This delay may have affected the reproducibility found in pelvic dimensions.

Available literature on male pelvimerty values was thoroughly explored to investigate global trends in these dimensions, however, male data was lacking compared to female data. The female pelvis has been of greater interest in research due to its obstetrical roles. Furthermore, when variability of the male pelvis is investigated, it is usually done so in the context of physical or forensic anthropology where intersex pelvic variation is of importance in sex estimation of skeletal remains. In such research, intrasex variability, and specifically that on males, is rarely reported or focused on.

It should be noted that a majority of published data that could be used when investigating global trends did come from anthropological research, which is largely performed on dry skeletal material. Thus, comparisons made between ecogeographical regions were done using pelvimetry data obtained through differing modalities (imaging and dry bone). Furthermore, when a dry bony pelvis is articulated with os coxal and sacral bones in anatomical position, the cartilaginous pubic symphysis between pubic bones, present in living individuals, is missing. Some studies make accommodation for this missing tissue value, however, other do not but it is worth noting that this value is very minimal at a few millimetres. Furthermore, data from lower latitudes was lacking compared to higher latitudes, leading to disproportional comparable data between latitudes. A larger portion of data found was from higher latitudes, specifically in the Northern hemisphere.

The clinical sample was limited to patients who have experienced procedural morbidity. The data was obtained retrospectively from clinical notes and several pertinent information could not be obtained as it was not recorded or documented. The clinical sample is small which decreases the generalisability of the data.

Clerical errors in transposing numbers is possible. This research involved computing a large number of measurement and errors may have occurred when noting pelvimetry measurements from the PISP software, as well as when collecting published data for world-wide pelvimetry values. However, care was taken to avoid such errors, and values were double checked.

### 5.1.5 Possible future research

Numerous opportunities exist for this research to be furthered. Measurements taken from the pelvic girdle focused canal diameters rather than height. Anatomical investigation could be furthered by including more measurements of pelvic height, which may provide more information regarding pelvic size and the effects of thermoregulation. As this population was found to display a relatively narrow pelvis in the transverse plane, it is expected that this would be accompanied by a relative increase in pubic height. Furthermore, pelvic shape changes relative to pelvis size could be investigated by employing geometric morphometrics, to gain more information in a 3D context.

Furthermore, a larger cohort with surgical complications should be reviewed to extend the parameters and factors assessed. These could include comparison of pelvic dimensions with intraoperative parameters (blood loss, operative time) as well as surgical oncological factors (quality of mesorectum or circumferential margin of the tumour). In addition, further patient parameters could be investigated, such as BMI and lifestyle. Due to the narrow nature of the South African bony pelvis, further comparisons would provide more information regarding key parameters that could be used as predictive values for measures of operative difficulty during TME. Such results may be of great value during preoperative planning.

Lastly, genetics plays a major role in anatomy as well as disease predisposition. A genetic component could be introduced to investigate genetic predisposition and heritability of colorectal cancer, the genetic effects on bony pelvic anatomy, and the relationship between genetics and ecogeographical patterns related to thermoregulation.

## 5.2 CONCLUSION

Colorectal cancer has been found to disproportionally affect South African males compared to females, while incidence continues to increase in both sexes. Surgical excision of colorectal tumours is a key factor in managing these conditions. The gold standard for excising rectal tumours is TME, involving removal of the entire rectum and its enveloping mesorectum from the spatially confined pelvic cavity. At TH, observations of increased difficulty during colorectal procedures on males led to the impression that South African males display a particularly narrow pelvic cavity. The size and shape of the pelvic girdle has evolutionarily been moulded by multiple influencing, and sometime contradictory, pressures. Males are known to naturally display narrower pelves than females. Thermoregulatory needs of the body have been thought to cause ecogeographical patterns in pelvic size, where population means lie on a latitude gradient of optimal phenotype. Literature regarding the size of specifically the male South African pelvis is lacking.

Thus, this study aimed to measure the dimensions of the bony pelvis in males from the Western Cape who have undergone potentially curative colorectal cancer surgery at TH, and to compare these results with other ecogeographical regions. Furthermore, it aimed to determine if an association exists between pelvic dimensions and morbidity documented in rectal cancers patients who have undergone TME at the hospital.

Pelvimetric results were obtained and compared to different regions, showing the South African male pelvic canal to be relatively narrow in the transverse plane compared to higher latitude regions. These transverse measurements displayed some ecogeographical pattern. Surgical complications associated with TME were investigated, with 20.59% of patients experiencing minor complications, 14.71% experiencing major complications, and a mortality rate of 2.94%. Pelvimetric measurements of the canal were thereafter compared with patient morbidity and significant differences were found between surgical complication groups in the inlet anteroposterior dimension. As the anatomical investigation found transverse pelvic plane to be narrow in our population, while the clinical investigation showed differences in inlet anteroposterior diameter between complication groups, no relationship between pelvic dimensions and patient morbidity were found. However, it has been noted by the colorectal team at TH that, if increased surgical difficulty is experiences during TME, it usually occurs during dissection in the transverse pelvic plane.

Therefore, our population was identified to have a transversely narrow pelvic canal which may introduce challenges during TME; however, morbidity data did not confirm this. A transversely narrow pelvis may increase difficulty in accurately visualising precise anatomy during mobilisation and excision of the mesorectum. This may decrease the quality of this structure, potentially leaving remaining mesorectum (and lymph nodes) in the pelvis, which is known to increase chances of LR. These results and their generalisability could be strengthened by increased sample size in the clinical investigation, as well as through approaching factor affecting TME in a more holistic approach, by factoring in intraoperative and surgical oncological parameters.

These findings are aimed to assist in identification of patients who present with a narrow pelvis prior to surgery, allowing for improved preoperative planning decisions regarding the most appropriate approach to rectal tumour excision based on individual patient anatomical features.

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# APPENDIX A

***Table A*** *Pelvimetric data for bi-iliac breadth and dimensions of pelvic inlet.*

| | *Location* | *Bi-iliac breadth (mm)* | *Inlet anteroposterior (mm)* | *Inlet transverse (mm)* |
|---|---|---|---|---|
| Ahrend *et al*., 2020 | Malasia | | 105±10 [n=50] | |
| Akiyoshi *et al*., 2009 | Tokyo, Japan | | 117 (101-135) [n=44] | |
| Boyle *et al*., 2004 | Leeds, UK | | 107,1±7,5 [n=63] | |
| Correia *et al*., 2005 | Coimbra, Portugal | | 99,68±10,15 [n=118] | 123,13±5,88 [n=118] |
| Decker *et al*., 2011 | South Florida | | 119,60±11,71 [n=40] | 122,34±8,69 [n=40] |
| Delprete, 2018 | Cleveland, Ohio | 250,9±12,8 [n=60] | 101,8±8,5 [n=60] | 113,9±7,3 [n=60] |
| | Cleveland, Ohio | 277,5±15,0 [n=60] | 105,0±8,5 [n=60] | 125,3±8,2 [n=60] |
| | Washington, DC | 250,8±15,0 [n=52] | 102,8±9,4 [n=52] | 114,4±8,1 [n=52] |
| | Washington, DC | 270,2±16,6 [n=52] | 107,3±8,4 [n=52] | 124,4±7,2 [n=52] |
| | Coimbra, Portugal | 260,9±13,5 [n=84] | 102,6±8,9 [n=84] | 121,0±6,4 [n=84] |
| | Spitalfields, East London | 264,3±14,7 [n=31] | 101,3±6,7 [n=31] | 121,9±6,1 [n=31] |
| Gruss *et al*., 2017 | Durham, North Carolina | 286±24(254-319) [n=12] | | |
| Jagesur *et al*., 2016 | Pretoria, South Africa | | 113,57±10,30 [n=20] | 112,04±10,22 [n=20] |
| | Pretoria, South Africa | | 123,44±11,32 [n=20] | 126,54±8,69 [n=20] |
| Kaufmann *et al*., 2016 | Erlangen, Germany | | | 128,21±7,99 [n=91] |
| Kolesova *et al*., 2017 | Latvia | | 119,2±10,2 [n=181] | 126,8±7,0 [n=181] |
| Kurki, 2011 | Democratic Republic of Congo | | 95,50±5,68 [n=6] | 103,17±6,59 [n=6] |
| | Philippines | | 91,25±4,68 [n=8] | 101,38±9,18 [n=8] |
| | Andaman Islands | | 94,71±5,25 [n=7] | 89,33±9,24 [n=6] |
| | South Africa | | 91,44±7,64 [n=16] | 96,14±8,23 [n=14] |
| | Tierra del Fuego, Argentina | | 101,43±5,61 [n=14] | 119,57±6,68 [n=14] |
| | Portugal | | 101,08±9,27 [n=40] | 118,65±5,60 [n=40] |
| | Australia | | 102,40±8,03 [n=10] | 111,00±5,81 [n=9] |
| | Northern African | | 98,43±8,26 [n=23] | 113,96±7,22 [n=24] |

| | *Location* | *Bi-iliac breadth (mm)* | *Inlet anteroposterior (mm)* | *Inlet transverse (mm)* |
|---|---|---|---|---|
| Kurki, 2007 | Cleveland, Ohio | | 104±7,6 [n=40] | 123±9,4 [n=40] |
| | Coimbra, Portugal | | 101±9,3 [n=40] | 119±5,6 [n=40] |
| Maass, 2012 | South Africa | | 102±9,8 [n=184] | 115±9,4 [n=184] |
| Ogiso *et al*., 2011 | Tokyo, Japan | | 110 (103-118) | 123 (119-127) |
| Schroeder *et al*., 1997 | Texas, USA | 294,4±18,6 | | 127,2±9,0 |
| Shimada *et al.*, 2017 | Tokyo, Japan | | 94,8 (63,7-127,0) [n=145] | 120,6(106,0-137,4) [n=145] |
| Steyn & Iscan, 2008 | Crete | 276,86±14,43 (n=84) | 103,21±8,54 (n=85) | 124,66±7,79 (n=85) |
| Torimitsu *et al*., 2015 | Tokyo, Japan | | | 120,10±6,79 (103,9-137,6) |
| Walrath & Glantz., 1996 | Pennsylvania, USA | | | 113 (95-137) |
| Wiid, 2016 | South Africa | | 102,35±11,30 (74,17-120,96) [n=31] | 112,39±6,78 (99,75-131,09) [n=31] |
| | South Africa | | 114,02±10,32 (90,79-133,27) [n=25] | 126,32±7,82 (107,99-138,74) [n=25] |
| | South Africa | | 105,12±9,13 (84,2-121,1) [n=21] | 113,03±6,44 (100,5-124,5) [n=21] |
| | South Africa | | 111,50±11,07 (95,8-142,2) [n=27] | 122,69±5,19 (113,4-132,2) [n=27] |
| Zhou *et al*., 2016 | Wenzhou, China | | 105,22±8,7 [n=38] | |

***Table B*** *Pelvimetric data for dimensions of pelvic midplane*

| | *Location* | *Midplane AP I (mm)** | *Midplane transverse I** | *Midplane AP II (mm)** | *Midplane transverse II (mm)** |
|---|---|---|---|---|---|
| Ahrend *et al*., 2020 | Malasia | | | | 88±8 [n=50] |
| Akiyoshi *et al*., 2009 | Tokyo, Japan | | | | 92 (80-105) [n=50] |
| Boyle *et al*., 2004 | Leeds, UK | | | | 90,5±8,1 [n=63] |
| Correia *et al*., 2005 | Coimbra, Portugal | | | 105,73±9,62 [n=118] | |
| Delprete, 2018 | Cleveland, Ohio | | 108,9±5,8 [n=60] | 115,2±7,5 [n=60] | 85,8±7,9 [n=60] |
| | Cleveland, Ohio | | 114,0±7,2 [n=60] | 112,3±8,1 [n=60] | 88,7±7,2 [n=60] |
| | Washington, DC | | 128,8±7,5 [n=52] | 116,3±8,4 [n=52] | 84,8±7,6 [n=52] |
| | Washington, DC | | 131,0±8,3 [n=52] | 114,2±7,3 [n=52] | 86,1±8,1 [n=52] |
| | Coimbra, Portugal | | 121,0±6,6 [n=84] | 110,0±7,2 [n=84] | 87,9±6,5 [n=84] |
| | Spitalfields, East London | | 121,5±6,0 [n=31] | 110,6±6,0 [n=31] | 89,2±8,0 [n=31] |
| Jagesur *et al*., 2016 | Pretoria, South Africa | | | | 78,84±9,23 [n=20] |
| | Pretoria, South Africa | | | | 90,03±6,81 [n=20] |
| Kaufmann *et al*., 2016 | Erlangen, Germany | | | | 91,19±7,64 [n=91] |
| Kolesova *et al*., 2017 | Latvia | 127,8±9,0 [n=181] | 113,8±7,2 [n=181] | 116,5±7,5 [n=181] | 93,6±8,4 [n=181] |
| Kurki, 2011 | Democratic Republic of Congo | | 88,83±3,91 [n=6] | 99,17±5,12 [n=6] | 76,64±3,44 [n=6] |
| | Philippines | | 89,17±7,42 [n=8] | 98,38±3,50 [n=8] | 73,73±5,09 [n=4] |
| | Andaman Islands | | 76,11±7,15[n=6] | 100,71±5,59 [n=7] | 63,18±6,87 [n=5] |
| | South Africa | | 86,24±5,55 [n=14] | 106,38±7,99 [n=16] | 80,59±7,16 [n=11] |
| | Tierra del Fuego, Argentina | | 103,41±4,53 [n=14] | 114,86±8,76 [n=14] | 88,48±6,86 [n=11] |
| | Portugal | | 107,46±5,97 [n=640] | 114,23±6,82 [n=40] | 86,69±7,08 [n=28] |
| | Australia | | 91,31±7,52 [n=8] | 106,30±5,87 [n=10] | 72,89±11,29 [n=8] |
| | Northern African | | 99,03±6,53 [n=23] | 110,33±7,41 [n=27] | 80,26±6,54 [n=17] |

| | *Location* | *Midplane AP I (mm)** | *Midplane transverse I** | *Midplane AP II (mm)** | *Midplane transverse II (mm)** |
|---|---|---|---|---|---|
| | Denmark | | 111,55±7,29 [n=8] | 117,63±9,05 [n=8] | 89,22±5,71 [n=7] |
| Kurki, 2007 | Cleveland, Ohio | | 108±6,8 [n=40] | 113±8,9 [n=40] | 86±7,0 [n=40] |
| | Coimbra, Portugal | | 107±6,0 [n=40] | 114±6,8 [n=40] | 87±7,1 [n=40] |
| Maass, 2012 | South Africa | | | | 86±8,3 [n=184] |
| Ogiso *et al*., 2011 | Tokyo, Japan | | | | 97 (91-100) |
| Torimitsu *et al*., 2015 | Tokyo, Japan | | | | 93,74±8,45 |
| Walrath & Glantz., 1996 | Pennsylvania, USA | | | | 80 (65-94) |
| Wiid, 2016 | South Africa | | | 111,61±7,76 (96,46-127,63) [n=31] | 81,91±8,43 (69,1-109,14) [n=31] |
| | | | | 128,66±9,10(111,52-154,49) [n=25] | 88,74±7,51 (74,91-103,77) [n=25] |
| | | | | 119,33±5,48 (111,5-129,5) [n=21] | 84,67±7,52 (72,4-103,8) [n=21] |
| | | | | 126,65±10,48 (107,1-152,2) [n=27] | 90,87±6,82 (74,9-103,9) [n=27] |
| Zhou *et al*., 2016 | Wenzhou, China | | | | 93,24±7,32 [n=38] |

*mean ± standard deviation (range) [sample size]

***Table C*** *Pelvimetric data for dimensions of pelvic outlet*

| | *Location* | *Outlet AP (coccyx) (mm)** | *Outlet AP (sacrum) (mm)** | *Outlet transverse (mm)** |
|---|---|---|---|---|
| Akiyoshi *et al.*, 2009 | Tokyo, Japan | 94 (79-111) [n=44] | | 108 (93-131) [n=50] |
| Boyle *et al.*, 2004 | Leeds, UK | 85,2±9,1 [n=63] | 109,6±7,1 [n=63] | 114,4±11,8 [n=63] |
| Correia *et al.*, 2005 | Coimbra, Portugal | | 109,22±8,10 [n=118] | 99,53±7,29 [n=118] |
| Delprete, 2018 | Cleveland, Ohio | | 109,4±7,8 [n=60] | 96,2±9,7 [n=60] |
| | Cleveland, Ohio | | 104,3±8,5 [n=60] | 103,0±9,8 [n=60] |
| | Washington, DC | | 109,4±9,7 [n=52] | 99,1±8,9 [n=52] |
| | Washington, DC | | 104,1±7,1 [n=52] | 105,1±9,3 [n=52] |
| | Coimbra, Portugal | | 102,1±7,5 [n=84] | 102,7±9,0 [n=84] |
| | Spitalfields, East London | | 101,5±6,9 [n=31] | 106,2±9,4 [n=31] |
| Decker *et al.*, 2011 | South Florida | 104,78±13,09 [n=40] | | |
| Jagesur *et al.*, 2016 | Pretoria, South Africa | 92,03±8,63 [n=20] | | 83,45±8,31 [n=20] |
| | Pretoria, South Africa | 95,00±8,78 [n=20] | | 98,34±10,00 [n=20] |
| Kolesova *et al.*, 2017 | Latvia | 96,0±7,4 [n=181] | | 103,5±9,3 [n=181] |
| Kurki, 2007 | Cleveland, Ohio | | 105±8,1 [n=40] | |
| | Coimbra, Portugal | | 108±6,7 [n=40] | |
| Kurki, 2011 | Democratic Republic of Congo | | 95,50±5,17 [n=6] | |
| | Philippines | | 94,75±3,45 [n=8] | |
| | Andaman Islands | | 98,83±4,83 [n=6] | |
| | South Africa | | 102,00±7,77 [n=15] | |
| | Tierra del Fuego, Argentina | | 111,57±8,81 [n=14] | |
| | Portugal | | 107,88±6,73 [n=40] | |
| | Australia | | 100,00±6,24 [n=9] | |
| | Northern African | | 103,27±7,13 [n=26] | |
| | Denmark | | 110,38±10,20 [n=8] | |

| | Location | Outlet AP (coccyx) (mm)* | Outlet AP (sacrum) (mm)* | Outlet transverse (mm)* |
|---|---|---|---|---|
| Maass, 2012 | South Africa | | 107±8,6 [n=184] | 103±12,2 [n=184] |
| Ogiso *et al*., 2011 | Tokyo, Japan | 100 (94-103) | | |
| Shimada *et al*., 2017 | Tokyo, Japan | 90,9(66,0-183,0) [n=145] | | 95,0(76,0-115,8) [n=145] |
| Torimitsu *et al*., 2015 | Tokyo, Japan | | | 94,01±10,31 (69,4-122,6) |
| Wiid, 2016 | South Africa | 79,76±8,37 (65,94-103,64) [n=31] | | 71,52±14,05 (46,82-125,80) [n=31] |
| | | 88,51±7,23 (77,46-103,38) [n=25] | | 81,66±8,63 (69,52-89,62) [n=25] |
| | | 83,06±8,81 (68,6-97,4) [n=21] | | 94,38±9,30 (80,2-122,6) [n=21] |
| | | 84,3±9,62 (65,1-108,7) [n=27] | | 105,72±9,19 (87,0-132,6) [n=27] |
| Zhou *et al*., 2016 | Wenzhou, China | 85,54±6,37 [n=38] | 107,96±6,74 [n=38] | 91,85±9,52 [n=38] |

*mean ± standard deviation (range) [sample size]

***Table D*** *Pelvimetric data for pubic bone*

| | Location | Pubic length (mm)* | Pubic width (mm)* | Pubic height (mm)* |
|---|---|---|---|---|
| Boyle *et al*., 2004 | Leeds, UK | | | 52,9±3,8 [n=63] |
| Decker *et al*., 2011 | South Florida | 91,62±8,23 [n=40] | | |
| Memarian *et al*., 2017 | Tehran, Iran | | 24,20±2,29 (18,5-32,7) [n=100] | 29,78±6,25 (16,7-46) [n=100] |
| Patriquin *et al*., 2004 | South Africa | | 20,92±3,04(12-29) | 38,98±3,48(29-50) |
| | | | 23,91±2,73(18-33) | 42,18±4,21(32-52) |
| Steyn & Iscan, 2008 | Crete | | | 40,86±3,38 (n=93) |
| Wiid, 2016 | South Africa | | | 45,26±4,20 (37,86-53,59) [n=31] |
| | | | | 49,01±4,27 (41,69-56,86) [n=25] |
| Zhou *et al*., 2016 | Wenzhou, China | | | 37,36±3,38 [n=38] |

***Table E*** *Ischial, acetabular, and greater sciatic notch (GSN) pelvimetry*

| | Location | Ischial length (mm)* | Acetabulum diameter (mm)* | GSN width (mm)* |
|---|---|---|---|---|
| Decker *et al*., 2011 | South Florida | 95,59±7,58 [n=40] | | |
| Kim *et al*., 2018 | Seoul, South Korea | | | 45,82±5,77 [n=101] |
| Patriquin *et al*., 2004 | South Africa | | | 36,96±4,62(28-49) |
| | | | | 43,03±4,99(30-56) |
| Soloman & Howie, 2014 | Adelaide, South Australia | | 50,7±3,4 [n=29] | |
| Steyn & Iscan, 2008 | Crete | | 54,59±3,07 (n=92) | 43,37±3,94 (n=93) |

*mean ± standard deviation (range) [sample size]

***Table F*** *Pelvimetric data for iliac breadth and os coxa height*

| | *Location* | *Iliac breadth (mm)** | *Os coxa height (mm)** |
|---|---|---|---|
| Decker *et al*., 2011 | South Florida | 164,85±11,85 [n=40] | 220,10±13,63 [n=40] |
| Giroux & Wescott, 2008 | Columbia, North West South America | | 210,3±14,6(159-238) [n=57] |
| | Columbia, North West South America | | 221,8±11,1(199-255) [n=92] |
| Kurki, 2007 | Cleveland, Ohio | | 215±11,1 [n=40] |
| | Coimbra, Portugal | | 212±8,0 [n=40] |
| Kurki, 2011 | Democratic Republic of Congo | | 175,71±9,20 [n=7] |
| | Philippines | | 180±16,37 [n=8] |
| | Andaman Islands | | 176,79±10,08 [n=7] |
| | South Africa | | 179,22±12,60 [n=28] |
| | Tierra del Fuego, Argentina | | 204,79±8,72 [n=14] |
| | Portugal | | 212,08±8,00 [n=40] |
| | Australia | | 196,91±6,01 [n=11] |
| | Northern African | | 201,04±8,07 [n=28] |
| | Denmark | | 223,17±5,97 [n=9] |
| Patriquin *et al*., 2004 | South Africa | 150,10±7,29(131-168) | 203,93±9,64(179-221) |
| | | 163,15±8,67(145-185) | 220,43±10,83(194-292) |

| | *Location* | *Iliac breadth (mm)** | *Os coxa height (mm)** |
|---|---|---|---|
| Soloman & Howie, 2014 | Adelaide, South Australia | | 193,0±11,0 [n=29] |
| Steyn & Iscan, 2008 | Crete | 159,26±7,52(n=94) | 214,63±9,20 (n=95) |

*mean ± standard deviation (range) [sample size]

# APPENDIX B

***Table G*** *Results of one-way ANOVA with post hoc Bonferroni test*

| *Dependent Variable* | *(I) Morbidity* | *(J) Morbidity* | *Mean Difference (I-J)* | *Std. Error* | *Sig.* | *95% Confidence Interval Lower Bound* | *95% Confidence Interval Upper Bound* |
|---|---|---|---|---|---|---|---|
| Inlet transverse | None | I | 6.56 | 5.86 | 1.00 | -10.43 | 23.54 |
| | | II | 3.46 | 6.57 | 1.00 | -15.60 | 22.52 |
| | | IIIb | 2.36 | 5.38 | 1.00 | -13.25 | 17.96 |
| | I | None | -6.56 | 5.86 | 1.00 | -23.54 | 10.43 |
| | | II | -3.10 | 7.89 | 1.00 | -25.98 | 19.78 |
| | | IIIb | -4.20 | 6.93 | 1.00 | -24.29 | 15.89 |
| | II | None | -3.46 | 6.57 | 1.00 | -22.52 | 15.60 |
| | | I | 3.10 | 7.89 | 1.00 | -19.78 | 25.98 |
| | | IIIb | -1.10 | 7.55 | 1.00 | -22.98 | 20.78 |
| | IIIb | None | -2.36 | 5.38 | 1.00 | -17.97 | 13.249 |
| | | I | 4.20 | 6.93 | 1.00 | -15.89 | 24.294 |
| | | II | 1.10 | 7.55 | 1.00 | -20.78 | 22.976 |
| Midplane transverse II | None | I | 6.66 | 5.05 | 1.00 | -7.97 | 21.29 |
| | | II | -5.56 | 5.67 | 1.00 | -21.99 | 10.86 |
| | | IIIb | -.66 | 4.64 | 1.00 | -14.11 | 12.78 |
| | I | None | -6.67 | 5.05 | 1.00 | -21.30 | 7.97 |
| | | II | -12.23 | 6.80 | .516 | -31.94 | 7.49 |
| | | IIIb | -7.33 | 5.97 | 1.00 | -24.64 | 9.99 |
| | II | None | 5.56 | 5.67 | 1.00 | -10.86 | 21.99 |
| | | I | 12.23 | 6.80 | .52 | -7.49 | 31.94 |
| | | IIIb | 4.90 | 6.50 | 1.00 | -13.95 | 23.75 |
| | IIIb | None | .66 | 4.64 | 1.00 | -12.78 | 14.11 |
| | | I | 7.33 | 5.97 | 1.00 | -9.99 | 24.64 |
| | | II | -4.90 | 6.50 | 1.00 | -23.75 | 13.95 |
| Outlet transverse | None | I | 5.64 | 6.11 | 1.00 | -12.07 | 23.34 |
| | | II | -4.21 | 6.85 | 1.00 | -24.08 | 15.65 |
| | | IIIb | .3257 | 5.61 | 1.00 | -15.94 | 16.59 |

| *Dependent Variable* | *(I) Morbidity* | *(J) Morbidity* | *Mean Difference (I-J)* | *Std. Error* | *Sig.* | *95% Confidence Interval* | |
|---|---|---|---|---|---|---|---|
| | | | | | | *Lower Bound* | *Upper Bound* |
| | | None | -5.64 | 6.11 | 1.00 | -23.34 | 12.07 |
| | I | II | -9.85 | 8.23 | 1.00 | -33.70 | 14.00 |
| | | IIIb | -5.31 | 7.23 | 1.00 | -26.26 | 15.64 |
| | | None | 4.21 | 6.85 | 1.00 | -15.65 | 24.08 |
| Outlet transverse | II | I | 9.85 | 8.23 | 1.00 | -14.00 | 33.70 |
| | | IIIb | 4.54 | 7.87 | 1.00 | -18.27 | 27.35 |
| | | None | -.33 | 5.61 | 1.00 | -16.59 | 15.94 |
| | IIIb | I | 5.31 | 7.23 | 1.00 | -15.64 | 26.26 |
| | | II | -4.54 | 7.87 | 1.00 | -27.35 | 18.27 |
| | | I | 21.83* | 6.20 | .01 | 3.86 | 39.80 |
| | None | II | 3.71 | 6.96 | 1.00 | -16.45 | 23.87 |
| | | IIIb | -1.68 | 5.70 | 1.00 | -18.19 | 14.83 |
| | | None | -21.83* | 6.20 | .01 | -39.80 | -3.86 |
| | I | II | -18.12 | 8.35 | .25 | -42.32 | 6.09 |
| Inlet anteroposterior | | IIIb | -23.51* | 7.33 | .02 | -44.77 | -2.25 |
| | II | None | -3.71 | 6.96 | 1.00 | -23.87 | 16.45 |
| | | I | 18.12 | 8.35 | .25 | -6.09 | 42.32 |
| | II | IIIb | -5.39 | 7.98 | 1.00 | -28.54 | 17.75 |
| | | None | 1.68 | 5.70 | 1.00 | -14.83 | 18.19 |
| | IIIb | I | 23.51* | 7.33 | .02 | 2.25 | 44.77 |
| | | II | 5.39 | 7.98 | 1.00 | -17.75 | 28.54 |
| | | I | 11.13 | 8.02 | 1.00 | -12.11 | 34.37 |
| | None | II | -1.99 | 9.00 | 1.00 | -28.07 | 24.08 |
| | | IIIb | -4.45 | 7.37 | 1.00 | -25.81 | 16.90 |
| | | None | -11.13 | 8.02 | 1.00 | -34.37 | 12.11 |
| | I | II | -13.13 | 10.80 | 1.00 | -44.43 | 18.18 |
| Midplane anteroposterior I | | IIIb | -15.59 | 9.49 | .69 | -43.08 | 11.91 |
| | | None | 1.993 | 9.00 | 1.00 | -24.08 | 28.07 |
| | II | I | 13.13 | 10.80 | 1.00 | -18.18 | 44.43 |
| | | IIIb | -2.46 | 10.33 | 1.00 | -32.39 | 27.48 |
| | | None | 4.45 | 7.37 | 1.00 | -16.90 | 25.81 |
| | IIIb | I | 15.59 | 9.49 | .69 | -11.91 | 43.08 |
| | | II | 2.46 | 10.33 | 1.00 | -27.47 | 32.39 |

| *Dependent Variable* | *(I) Morbidity* | *(J) Morbidity* | *Mean Difference (I-J)* | *Std. Error* | *Sig.* | *95% Confidence Interval Lower Bound* | *Upper Bound* |
|---|---|---|---|---|---|---|---|
| Midplane anteroposterior II | None | I | 7.52 | 5.43 | 1.00 | -8.22 | 23.26 |
| | | II | -4.36 | 6.09 | 1.00 | -22.02 | 13.30 |
| | | IIIb | 1.03 | 4.99 | 1.00 | -13.43 | 15.49 |
| | I | None | -7.52 | 5.43 | 1.00 | -23.26 | 8.22 |
| | | II | -11.88 | 7.31 | .71 | -33.08 | 9.32 |
| | | IIIb | -6.49 | 6.42 | 1.00 | -25.11 | 12.13 |
| | II | None | 4.36 | 6.09 | 1.00 | -13.30 | 22.02 |
| | | I | 11.88 | 7.31 | .71 | -9.32 | 33.08 |
| | | IIIb | 5.39 | 6.99 | 1.00 | -14.88 | 25.67 |
| | IIIb | None | -1.03 | 4.99 | 1.00 | -15.49 | 13.43 |
| | | I | 6.49 | 6.42 | 1.00 | -12.13 | 25.11 |
| | | II | -5.39 | 6.99 | 1.00 | -25.67 | 14.88 |
| Outlet anteroposterior | None | I | 9.01 | 6.02 | .89 | -8.45 | 26.46 |
| | | II | 1.46 | 6.79 | 1.00 | -18.13 | 21.05 |
| | | IIIb | 4.26 | 5.53 | 1.00 | -11.79 | 20.30 |
| | I | None | -9.01 | 6.02 | .89 | -26.46 | 8.45 |
| | | II | -7.55 | 8.11 | 1.00 | -31.07 | 15.97 |
| | | IIIb | -4.75 | 7.13 | 1.00 | -25.41 | 15.91 |
| | II | None | -1.46 | 6.76 | 1.00 | -21.05 | 18.13 |
| | | I | 7.55 | 8.11 | 1.00 | -15.97 | 31.07 |
| | | IIIb | 2.80 | 7.76 | 1.00 | -19.69 | 25.29 |
| | IIIb | None | -4.26 | 5.54 | 1.00 | -20.30 | 11.79 |
| | | I | 4.75 | 7.13 | 1.00 | -15.91 | 25.41 |
| | | II | -2.80 | 7.76 | 1.00 | -25.29 | 19.69 |
| Midplane transverse 1 | None | I | 6.69 | 7.53 | 1.00 | -15.14 | 28.52 |
| | | II | -3.55 | 8.45 | 1.00 | -28.04 | 20.95 |
| | | IIIb | -2.71 | 6.92 | 1.00 | -22.77 | 17.35 |
| | I | None | -6.69 | 7.53 | 1.00 | -28.52 | 15.14 |
| | | II | -10.23 | 10.15 | 1.00 | -39.64 | 19.17 |
| | | IIIb | -9.4000 | 8.91 | 1.000 | -35.23 | 16.43 |
| | II | None | 3.5476 | 8.45 | 1.000 | -20.95 | 28.04 |
| | | I | 10.2333 | 10.15 | 1.000 | -19.17 | 39.64 |
| | | IIIb | .8333 | 9.70 | 1.000 | -27.29 | 28.95 |
| | IIIb | None | 2.7143 | 6.92 | 1.000 | -17.35 | 22.78 |
| | | I | 9.4000 | 8.9111 | 1.000 | -16.43 | 35.23 |
| | | II | -.8333 | 9.7011 | 1.000 | -28.95 | 27.29 |